A Report for

National Association of Broadcasters

Regarding

High-VHF Field Measurements of ATSC 3.0 Digital Television Signals in Cleveland, Ohio

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EXECUTIVE SUMMARY

BACKGROUND

This document describes the National Association of Broadcasters Labs (**NAB**) digital television (**DTV**) field test results obtained by Meintel, Sgrignoli, and Wallace (**MSW**) in **January** and **February 2016.** The DTV field test was conducted in Cleveland, Ohio under the auspices of a Federal Communications Commission (**FCC**) 6-month experimental Special Temporary Authorization (**STA**).

The field test employed the transmission facilities of the Tribune-owned WJW television station that serves the Cleveland market with digital television on physical CH 8. The DTV field test was performed on an unallocated high-VHF television channel (CH 9), with the cooperation of WTOV (Sinclair Broadcasting), WOIO (Raycom Media), and CBET (Canadian Broadcasting Company), who allowed the Cleveland field test to be performed on CH 9, and accepted limited interference in their service area between the weekday hours of 8:00 am and 5:00 pm during the test period.

The purpose of the field test was to evaluate in various environments the high-VHF *fixed* and *indoor* performance of the newly proposed Advanced Television System Committee (ATSC) transmission system called ATSC 3.0 (ATSC3) compared to the performance of the current ATSC 1.0 (ATSC1) transmission system. Specifically, NAB desired to perform a comparison of both *coverage* (field strength) and *service* (reception) of these two DTV transmission systems utilizing longer wavelength (low-frequency) high-VHF frequencies. Additionally, evaluation of different likely ATSC3 operating modes was deemed to be useful in understanding possible future business opportunities for broadcasters. NAB believes that having this field test data would be beneficial to broadcasters, especially in light of inducements to more intensively use the high-VHF band.

The current ATSC1 transmission system is based on the single-carrier 8-VSB modulation scheme while the proposed ATSC3 transmission system is based on the multi-carrier COFDM modulation scheme. Two parts of the ATSC3 physical layer have been adopted by ATSC as *candidate* standards on May 6, 2015 and September 28, 2015, and are currently being evaluated by the industry for adoption as an ATSC *proposed* standard, and then subsequently an ATSC *final* standard within the **2016** calendar year.

OBJECTIVES

Given the upcoming broadcast spectrum reduction that will take place after repacking the spectrum following the 2016 600 MHz Spectrum Incentive Auctions, the VHF band is likely to be utilized more fully. Therefore, knowledge of real-world ATSC3 field performance in the high-VHF band is a desired objective in order to allow broadcasters to make informed decisions regarding future operation in this band.

This high-VHF field test had two major objectives:

(1): The first objective was to evaluate *comparative* fixed high-VHF outdoor data service (*i.e.*, signal reception) of the ATSC1 and ATSC3 digital transmission systems using an *outdoor* consumer receive antenna at both 15' AGL and 30' AGL heights in various environments in the Cleveland area. Additionally, *three* different ATSC3 modes were selected for performance comparison purposes to ATSC1.

(2): The second objective was to evaluate *comparative* fixed high-VHF indoor data service (*i.e.*, signal reception) of the ATSC1 and ATSC3 digital transmission systems using an *indoor* consumer receive antenna inside buildings (typically on a lower level floor) in various environments in the Cleveland area.

Additionally, the same *three* different ATSC3 modes selected for the outdoor testing were also selected for indoor performance comparison purposes to ATSC1.

FIELD TEST PLAN

In order to gain additional knowledge and experience, especially with noise in in the use of the VHF television band for ATSC3 operations, NAB planned a field test using the Cleveland WJW test transmitter site. The FCC authorized NAB temporary use of CH 9 in Cleveland at an effective radiated power (ERP) of 10 kW. The test employed WJW's side-mounted CH 8 backup antenna and feedline (albeit, mounted 250' and 130' *lower* than the antennas of adjacent channels 8 and 10, respectively) operating on CH 9. This lower CH 9 antenna height is one factor that caused significant upper and lower first adjacent channel interference D/U ratios to occur at some of the field test sites.

Various companies provided transmission and test equipment for ATSC1 and ATSC3 signal generation and reception during the field test: GatesAir provided the transmitter, Dielectric provided the mask filter, ETRI provided the ATSC3 exciter and receiver prototypes, TeamCast provided the transmitter pre-corrector (that together with the emission mask filter reduced out-of-band splatter to within the FCC limits), and MSW provided the field test truck with a 30' AGL pneumatic mast and equipment for gathering the reception data in the field (including a directional consumer receive antenna for outdoor testing, a bi-directional dipole-like consumer antenna was used for indoor testing, and a 2009 ATSC1 coupon eligible converter box receiver).

Another adjacent-channel interference factor was that the ETRI prototype ATSC3 receiver did *not* have a conventional front-end high-VHF tuner similar to existing ATSC1 receivers or what would be expected to be employed in a mature ATSC3 consumer design since there is no need for such a tuner in Korea where the high-VHF band is NOT allocated for television transmission. A high-VHF tuner was assembled and provided by ETRI, but was found to have poor adjacent channel performance that tolerated only D/U ratios up to -12 to -15 dB rather than D/U ratios better than -27 dB as do existing ATSC1 receivers. Consequently, it was determined that adjacent channel interference did limit ATSC3 signal reception in some test locations, and this was accounted for in some of the field test data analysis.

The field test plan called for gathering test site reception data such as field strength, reception status (successful or not), signal margin (if any), and error threshold signal-to-noise ratio (**SNR**) as measured in the prototype ATSC3 receiver. While ATSC1 threshold was determined by viewing video, ATSC3 data threshold was determined in the test truck by viewing a forward error correction (FEC) block counter rather than viewing video. Threshold was defined by the maximum amount of signal attenuation that could be tolerated and still provide *error-free* reception.

A total of **88** *outdoor* test sites were visited (**59** sites on **5** radials and **29** sites on **2** grids) that covered a variety of terrain over a **60**-mile radius from the WJW transmitter in Parma, Ohio, and therefore provided meaningful results. Only **4** *indoor* test sites were visited due to a lack of time, and therefore provided anecdotal information. The outdoor tests collected data at both 30' AGL and 15' AGL receive antenna heights, while the indoor tests collected separate data with horizontally-polarized and vertically-polarized antennas.

Four test signals were evaluated in this field test: ATSC1 and 3 modes of ATSC3:

(1) Fixed reception with equivalent TOV (but higher ATSC3 data rate)
(2) Fixed reception with equivalent payload rate (with lower ATSC threshold)
(3) Robust reception (e.g., for severe indoor conditions with very low ATSC3 threshold and much lower ATSC data rate)

RESULTS

(1) **Outdoor Reception Service:** When both outdoor receive antenna heights are considered, the two higher data rate ATSC3 signals that had comparable thresholds to ATSC1 (1.2 dB higher and 0.6 dB lower) had slightly *lower* overall service rates (13 % and 8 %, respectively) than ATSC1. The slight difference is likely due to the use of a prototype ATSC3 receiver rather than a fifth-generation ATSC1 receiver. The low-data-rate robust ATSC3 signal had the best overall service rate by far (> 92%), surpassing ATSC1 reception by 13% that included test sites 60 miles from the transmitter. The relative threshold values along with the ATSC3 receiver front-end robustness issue explains these field test service results. Analysis showed that the ATSC3-A and ATSC3-B service numbers *most likely* would have improved by 5% to 8% if a more robust ATSC3 tuner were used at test sites with significant adjacent channel interference.

(2) **Outdoor Reception Margin:** The two high data rate ATSC3 signals had comparable margin values to ATSC1 since they had comparable threshold values to ATSC1, and the low data rate robust ATSC3 signal had significantly better margin (12 – 15 dB). Data analysis showed the usual dB-for-dB reduction in margin versus field strength. The data outliers occurred at those sites where failure occurred (*i.e.*, zero margin) due to external interference such as co-channel or adjacent channel interference resulting from fragile overload performance of the prototype ATSC3 front-end tuner hardware.

(3) **Outdoor System Performance Index (SPI):** When evaluating only sites that had signal levels above the required minimum sensitivity level for SPI, the higher data rate ATSC3 signals were successfully received at ≈80% of the sites at 30' AGL and ≈72% at 15' AGL. The low-data rate robust mode signals were successfully received at ≈96% and 90% at 30' AGL and 15' AGL, respectively. These numbers would also increase if a more robust ATSC front-end tuner were used.

(4) **Threshold SNR:** Internally-measured ATSC3 prototype threshold SNR values were essentially the same (within 0.5 dB) as those measured in the laboratory, which emphasizes the fact that the ATSC receiver was able to maintain good weak signal performance with little threshold degradation in the presence of whatever impairments (e.g., multipath) or interference (e.g., co-channel, adjacent channel, impulse noise) was experienced in the field.

(5) **Indoor Reception Service:** Indoor testing performed at the end of the outdoor test as time allowed was only meant to be anecdotal, which is why only 4 commercial test sites were visited. The indoor locations within the buildings under test were either in the basement, first floor, or second floor. Only 1 site had decent reception for the high-data rate modes (ATSC1 or ATSC3), with the others either having too little signal on the lower floors inside the buildings. However, the low-data rate robust ATSC3 mode was able to be received in all 4 locations, indicating that modes similar to the one tested should provide very good service indoors. Testing in viewer homes (e.g., single family residences or apartments/condos) was ***not*** part of this field test, so information on impulse noise and broadband digital circuitry interference into ATSC3 from inside the home has *not* been evaluated.

(6) **Layered Data Multiplexed (LDM):** The LDM fixed and mobile field tests were performed by ETRI engineers (with truck and hardware support from MSW). ETRI subsequently evaluated the data and summarized the results that are contained in their entirety in **Appendix 5** of this report.

CONCLUSIONS

The NAB high-VHF Cleveland field test of the proposed ATSC system was deemed to be successful and very educational. The newly proposed ATSC3 system performed well at high-VHF frequencies and therefore provides encouragement for its use in this frequency band. The two higher data rate ATSC3 transmission modes had slightly lower overall successful service rates than ATSC1. However, these numbers likely would have improved if a more robust tuner were used for testing, and the lower-data rate robust ATSC3 signal performed much better than ATSC1. From these results, use of this long-wavelength television band for fixed outdoor and indoor reception of ATSC3 appears acceptable, although as with ATSC1, ATSC3 is not immune to reception problems caused by low signal levels or RF interference.

PURPOSE

The purpose of this document is to describe and explain the National Association of Broadcasters Labs (**NAB**) digital television (**DTV**) field test results obtained by Meintel, Sgrignoli, and Wallace (MSW). The DTV field test was conducted under the auspices of a 6-month (11/15/15 to 5/16/16) experimental Special Temporary Authorization (**STA**) #1158-EX-ST-2015 in Cleveland, Ohio from January 25, 2016 through February 25, 2016. The field test employed the transmission facilities of Tribune-owned WJW television station that serves the Cleveland, Ohio market.

The goal of the field test was to evaluate in various environments the high-VHF *fixed* and *indoor* performance of the newly proposed Advanced Television System Committee (**ATSC**) transmission system called ATSC 3.0 (**ATSC3**) compared to the performance of the current ATSC 1.0 (**ATSC1**) transmission system. Specifically, NAB desired to perform a comparison of both *coverage* (field strength) and *service* (reception) of these two DTV transmission systems utilizing longer wavelength (low-frequency) high-VHF frequencies, especially with emphasis on noise issues encountered in this band. Additionally, evaluation of various likely ATSC3 operating modes was judged to be very helpful in understanding possible future business opportunities for broadcasters. NAB believes that having this field experience would be beneficial to the industry in light of inducements to using the high-VHF band.

In addition to background information, this document describes the field test goals and objectives, test equipment, test plan and procedures, raw data, and data analysis.

BACKGROUND INFORMATION

The current ATSC1 transmission system[1] is based on the single-carrier 8-VSB modulation scheme while the proposed ATSC3 transmission system[2] is based on the multi-carrier COFDM modulation scheme. The two parts of the ATSC3 physical layer have been adopted by ATSC as *candidate* standards on May 6, 2015 and September 28, 2015, and are currently being evaluated by the industry for subsequent adoption to a *proposed* standard, and then adoption to a *final* standard before the end of 2016.

Given the upcoming broadcast spectrum reduction that will take place after a spectrum repack following the 600 MHz Spectrum Incentive Auctions[3], scheduled for 2016, both VHF and UHF television bands must be utilized to their fullest. Some UHF ATSC3 field testing has been already performed. Therefore, knowledge of real-world ATSC3 field performance in the longer wavelength high-VHF band is now an objective in order to allow broadcasters to make informed decisions regarding any potential move to this band. In order to gain knowledge and experience, especially with noise in this particular television band, NAB planned a field test using the test transmitter site of TV Station WJW, Channel 8, Cleveland, Ohio.

The WJW test site is advantageous since it not only has a UHF transmitter, feedline, and antenna available (sitting idle from its use during the 10-year digital television (DTV) transition), it also has a high-VHF feedline that can operate on Channel 9 and a relatively broadband side-mounted high-VHF antenna available during daytime hours, thus avoiding the limited and inconvenient situation of overnight-only testing. Also, the greater Cleveland metropolitan area has a variety of terrain that provides for good field testing: hills to the south and southeast, flat lands to the west, and tall buildings in the "concrete canyons" of the downtown area. Further future testing of single frequency networks

[1] "ATSC Digital Television Standard: Part 2 – RF/Transmission System Characteristics", Doc A/53, Part 2:2007, January 3, 2007, www.atsc.org.

[2] See ATSC *candidate* standards A/321 Part 1 System Discovery and Signaling (5/6/15), and *proposed* standard A/322 Physical Layer Protocol (9/28/15), www.atsc.org.

[3] FCC, "Broadcast Television Spectrum Incentive Auction NPRM, Docket 12-268, September 28, 2012.

(SFN) may also be possible using a secondary transmitter and antenna on WJW's studio-to-transmitter link (STL) tower next to its studio in downtown Cleveland.

OBJECTIVES

The 5-week field measurement program undertaken by **NAB** and implemented by MSW in January and February 2016 had *multiple* objectives:

(1): The first objective was to evaluate *comparative* fixed high-VHF outdoor data service (i.e., signal reception) of the ATSC1 and ATSC3 digital transmission systems using an outdoor consumer receive antenna at both 15' AGL and 30' AGL heights in various environments in the Cleveland area. Additionally, *three* different ATSC3 modes were selected for performance comparison purposes to ATSC1: (a) a higher data rate but approximately equivalent TOV threshold mode, (b) an equivalent payload data rate but slightly lower TOV threshold mode, and (c) a low data-rate robust mode.

(2): The second objective was to evaluate *comparative* fixed high-VHF indoor data service of the ATSC1 and ATSC3 digital transmission systems using a consumer indoor consumer receive antenna inside buildings (typically on a lower level floor) in various environments in the Cleveland area. Additionally, the same *three* different ATSC3 modes selected for outdoor testing were also selected for indoor performance comparison purposes to ATSC1.

Note that while the outdoor testing was planned to have a substantial number of test sites that included random selection in geographically diverse areas on periodically-spaced radials and grids throughout the Cleveland DMA, the indoor testing was *not* designed or intended to be a definitive test given the limits of the testing (*e.g.*, CH 9 airtime was limited to weekdays between the hours of 8:00 am and 5:00 pm, and the prototype ATSC3 receiver availability was limited to the end of February due to prior commitments). Rather, the indoor testing was based on general anecdotal tasks performed on a small number of available test sites that provided real-world experience in the high-VHF television band rather than the past performance evaluation in the UHF band.

FIELD TEST TRANSMITTER DESCRIPTION

The NAB field test was performed using the WJW digital transmitter facilities that are located in Parma, Ohio, a large suburb about 10 miles southwest of downtown Cleveland. The station's studio is just northeast of downtown Cleveland, on the shores of Lake Erie. While WJW was transmitting their daily ATSC1 commercial television signal on high-VHF CH8, the NAB ATSC1 and ATSC3 field test signals were transmitted (alternately) on CH 9 using the WJW backup antenna and feedline that was repurposed from CH 8 to CH 9 specifically for this field test.

Table A1-1 in **Appendix 1** contains the summary of field test transmitter site details, while a simplified block diagram of the transmitter is shown in **Figure A1-1**. The primary CH 8 WJW LARCAN transmitter (**Figure A1-2a**) and ERI emission mask filter (**Figure A1-2b**) reside at their Parma transmitter site. The temporary CH 9 NAB test transmitter and emission mask filter were located in the same building for the purpose of the Cleveland ATSC3 field test. A 24-module solid-state GatesAir transmitter (**Figure A1-3a**), which included an ATSC1 exciter and internal RF switch for exciter redundancy, fed a Dielectric interdigital emission mask band-pass filter (**Figure A1-3b**) to drive the WJW backup antenna. This *side*-mounted CH 8 3-bay batwing backup antenna had enough bandwidth to operate adjacently on CH 9 for this field test, and was located on the same tower about 240' *below* the primary top-mounted WJW CH 8 traveling wave antenna.

Due to the built-in exciter redundancy that is part of the GatesAir CH 9 test transmitter (close-up shown in **Figure A1-4**), it had the capability of receiving an external RF signal from a separate exciter. Therefore, the ATSC1 signal was created in the GatesAir 8-VSB modulator while the ATSC3 signal was created by the combination of an ETRI modulator and a TeamCast upconverter/pre-corrector (**Figure A1-5**). The internal GatesAir RF switch was remotely controlled via an Internet signal sent from the MSW field test truck to the transmitter GUI software to switch between these ATSC1 and ATSC3 sources. Additionally, the ATSC3 prototype exciter had the capability, via computer control, to provide three different ATSC3 signal modes that were required for the comparative field testing. Switching among the three ATSC3 modes was also accomplished by remote control (Ultimate VNC on ETRI computer) from the MSW field test truck (Cell Phone MiFi). The three different ATSC3 modes are described in detail in a subsequent section of this report.

The CH9 transmitter power output (TPO) was approximately 4 kW, which fed the harmonic and emission mask filters, 50-Ohm 3-1/4" rigid antenna coaxial feedline, and side-mounted 3-bay batwing antenna (horizontally polarized only). The net result was an effective radiated power (ERP) output of approximately **10 kW**. The CH 9 antenna, which was located about **587'** above ground level (AGL) with a height above average terrain (HAAT) of about **872.5'**, had a *non*-directional radiation pattern that provided signal coverage throughout the Cleveland metropolitan area.

The transmitted NAB in-band signal quality SNR for the ATSC1 test signal and the three ATSC3 test signals was better than 30 dB. The out-of-band spectral splatter for the ATSC1 test signal (see **Figure A1-6a**) and the ATSC3 test signal (see **Figure A1-6b**) was better (≈ -54 dBc for ATSC1 and ≈ -52 dBc for ATSC3) than that required by the FCC emission mask (≤ -47 dBc) [4] [5] for the 1st 500 kHz sub-band). Each of the three ATSC3 signal modes had an occupied bandwidth of approximately 5.832 MHz while the ATSC1 signal had the standard Nyquist/Noise bandwidth of 5.381 MHz.

CHANNEL INTERFERENCE ISSUES

It should be noted that a full-time signal on CH 9 in Cleveland is *not* allocated by the FCC. Therefore, other CH 9 co-channel television signals (Windsor, ON and Steubenville, WV) were present in parts of the service area evaluated during this NAB field test, and consequently provided the opportunity to assess co-channel interference.[6] These co-channel interference signals did, in fact, affect reception of the ATSC1 and ATSC3 test signals in some areas (east of transmitter), and therefore should be accounted for in the evaluation of the overall test data.

On a related note, potentially interfering signals on first adjacent channels also existed during this field test. The first is a lower adjacent channel signal on CH 8 (Cleveland WJW co-sited with the CH 9 test signal) and an upper adjacent channel signal on CH 10 (Cleveland, WOIO, sited about **1** to **2** miles away). Both of these adjacent channel television signals had very comparable ERP values to the CH 9 NAB test signals, but were transmitted from top-mounted antennas with higher HAAT values (**250'** higher for WJW on CH 8 and **130'** higher for WOIO on CH 10). Therefore, while signal strengths were comparable at many sites (especially far from these three signal sources), there were some sites where the adjacent channel signal levels relative to the desired CH 9 test signal were significantly higher (*i.e.*, 10 to 20 dB higher). Some of these sites with strong adjacent channel experienced reduced reception

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[4] FCC 47CFR 73.622(h).

[5] "IEEE Recommended Practice for Measurement of 8-VSB Digital Television Transmission Mask Compliance for the USA", RF Standards Committee G-2.2, Page 8-9, IEEE, August 9, 2006.

[6] Operation of the Channel 9 test facility in Cleveland was fully coordinated with both co-channel stations because of predicted interference.

margin or even failed reception, primarily due to the fact of less than robust high-VHF tuner performance of the prototype ATSC3 receiver.

FIELD TEST VEHICLE DESCRIPTION

A summary of test equipment and hardware contained in the MSW field test van is listed in **Table A2-1** in **Appendix 2**. **Figure A2-1a** illustrates the test truck's system block diagram of the 50-Ohm reference test equipment used for *fixed outside* measurements (both 30' AGL and 15' AGL) that employed a directional consumer receive antenna. **Figure A2-1b** illustrates the block diagram used for fixed *indoor* measurements that employed a bi-directional consumer receive antenna that was mounted on a tripod, and brought inside buildings along with the other test equipment.

Figure A2-2 contains exterior and interior pictures of the MSW test van. The truck design followed the concepts put forth in the FCC's Office of Engineering and Technology (OET) Bulletin 69 [7]with regard to planning factors.

A GPS unit (Garmin GPS-76) with an external GPS antenna mounted on top of the van (Garmin GA-27C) was used to determine the exact location (latitude and longitude coordinates) of each test site as well as its distance and bearing from the Parma transmitter site. All data was recorded in a *custom*ized Excel spreadsheet file running on a laptop PC in the truck. A spectrum analyzer (R&S FSH-8) was employed in the van (fixed outdoor test) and in the buildings (indoor test) to measure average power signal levels in a 6 MHz bandwidth by using bandpower markers, which was then used with the known system gain and antenna gain to calculate field strength.

The van's 30' extendable pneumatic mast had a broadband (CH 7 – CH 51) Digitenna DUV-S directional consumer antenna mounted on it that was raised to 30' AGL for the primary outdoor measurements (and then lowered to 15' AGL for the secondary outdoor measurements). With the use of a mast-mounted rotor, the antenna was remotely rotated from within the truck in order to optimize the antenna pointing for maximum desired signal level before performing the 30' AGL and 15' AGL *outdoor* measurements. The DUV-S antenna has a forward gain of *about* **2.1 dB** at CH 9, and simulates to some degree what a viewer might use on the roof or in the attic for outdoor reception at a single-family residence. This consumer antenna is shown in **Figure A2-3a**.

A portable tripod was used to support a broadband (CH 7 – CH 51) Digitenna DUV-I bi-directional (i.e., dipole) antenna that was manually rotated in order to perform the indoor measurements. The DUV-I antenna has a forward gain of *about* **-0.7 dB** at CH 9. This antenna simulates to some degree what a viewer might use for *indoor* reception inside a single-family home or an apartment/condominium. This consumer antenna is shown in **Figure A2-3b**.

Each of these consumer antennas used in the field test was calibrated once at the desired RF test channel for gain above a dipole antenna (in dBd), just *before* the field test began. The gain calibration was performed in Cleveland by comparison with a very accurate commercial reference dipole antennas (AH Systems **TV-1** for the VHF band).

The Korean organization ETRI that provided the ATSC3 prototype receiver did *not* have a high-VHF tuner available since the VHF band is *not* used for broadcast television in Korea. Therefore, they assembled a tuner of sorts that required an *external* narrow band-pass filter that would provide significant rejection to adjacent and image frequency channels, especially lower (CH 8) and upper (CH 10) first adjacent channels. This filter had about 0.2 dB of average insertion loss over the 6 MHz CH 9

[7] OET Bulletin #69, "Longley-Rice Methodology for Evaluating TV Coverage and Interference", Section III: Part2, Table 5A, Page 8, Feb 6, 2004.

band. Additionally, it provided an average lower and upper adjacent 6 MHz channel loss of **22.2 dB** and **20.9 dB**, respectively. Therefore, a significant amount of out-of-band rejection (as well as image rejection) was provided by this filter, which was helpful considering the fact there was a lower adjacent channel 8 (**WJW**) and upper adjacent channel 10 (**WOIO**) present in certain parts of the service area during this field test. However, the performance of the "makeshift" high-VHF tuner was still not as robust as that of a conventional DTV receiver, and therefore had overload limitations that affected reception performance at some of the test sites. To provide a fair comparison for both ATSC1 and ATSC3 signal testing, this band-pass filter was placed after the coaxial cable feedline and before the field test truck's RF amplifier so that both DTV receivers benefited from its presence. A picture of the bandpass filter (**Figure A2-4a**) and its magnitude response (**Figure A2-4b**) is shown in **Appendix 2**.

Continuing with the truck's receive system description, the calibrated DUV-S antenna fed a coaxial cable (Belden RG-214) that carried the antenna signal through a CH 9 band-pass filter to the "works-in-a-drawer" (WIAD) unit. The WIAD unit contained a 1-dB step variable attenuator (JFW 50DR-001) covering a range from 0 dB to 110 dB followed by a robust ($IP_3 > +38$ dBm), low-noise (NF < 4 dB) amplifier (Mini-Circuits ZFL-1000VH) before splitting the signal four ways (Mini-Circuits ZFSC-4-1) to allow connection of two test DTV receivers as well as a spectrum analyzer (Rohde & Schwarz FSH-8). The fourth splitter output was unused and terminated in 50 Ohms.

The ATSC1 receiver was a Zenith coupon eligible converter box (CECB) manufactured for the 2009 analog television turnoff date. Since this unit was a consumer device, no FEC error count or internal SNR values were available for engineering evaluation. Therefore, a video picture ("Eggplant Parmesan" cooking show video loop) was used to determine the ATSC1 threshold.

The ATSC3 prototype receiver was designed and assembled for compatibility to the newly proposed ATSC3 system, particularly the reception of the three specific modes selected for this field test. The receiver provided some basic data to the monitor computer, such as the number of uncorrected FEC data errors every 0.5 second and an internal SNR calculation obtained from the received signal after equalization. The FEC error values provided direct evaluation of the error threshold, avoiding the necessity of watching HD pictures. The SNR value provided an indication of the noise threshold conditions in which the receiver was able to operate error-free.

Pictures of these two receivers are shown in **Figure A2-5**. Various performance parameters for the ATSC1 and ATSC3 digital receivers are shown in **Table 2**. As can be seen from this data, the ATSC3 prototype has about **0.5 dB** to **1.1 dB** of implementation error for an unimpaired signal in white noise conditions.

Table 2 ATSC1 and ATSC3 receiver thresholds and sensitivities.

DTV Receiver Mode	Field Test Receiver	Data Rate (Mbps)	AWGN Threshold		Signal Sensitivity	
			Ideal[1] (dB)	Actual[2] (dB)	Actual[3] (dBm)	Actual[4] (dBµV/m)
ATSC1	Zenith CECB	19.3927	15.00	14.9	-72.9	37.4
ATSC3-A	ETRI Prototype	23.1667	14.98	16.1	-71.8	38.5
ATSC3-B	ETRI Prototype	19.0369	13.64	14.1	-73.7	36.6
ATSC3-C	ETRI Prototype	3.2333	-0.90	-0.3	-89.9	20.4

[1] Theoretical (ideal) additive white Gaussian noise threshold values determined from computer simulation.
[2] White Gaussian noise threshold values determined from actual lab measurements in field test truck.
[3] Signal power sensitivity values determined from actual lab measurements in field test truck.
[4] Signal field strength sensitivity values determined from actual lab measurements in field test truck plus field strength calculations.

With the known possibility of first adjacent channel interference from CH 8, CH 10, or both, a brief laboratory-like interference test was performed in the truck on the ATSC3 prototype receiver. It was determined from this measurement that the D/U ratio for *one* adjacent channel interferer (either CH 8 or CH 10) was only about -10 dB to -12 dB (rather than the -27 dB value in the FCC planning factors), which means that there was a good chance that reception could be limited during the field test. Consequently, it was determined that adjacent channel interference did limit ATSC3 signal reception in some locations. However, it is anticipated that a consumer ATSC3 receiver would exhibit similar adjacent channel performance characteristics as the ATSC1 receiver, and those locations would have had reception with a better-performing tuner.

The antenna *dipole factor*, K, which varies inversely with channel frequency, allows direct mathematical conversion between electromagnetic field strength (in dBμV/m) at the antenna input and signal power (in dBm) at its output, and is known for each RF test channel. The DTV field strength was calculated at each site by using the antenna gain (in dBd), the dipole factor (in dBμV/m-dBm), truck system gain (in dB, which includes the coaxial cable loss, amplifier gain, and splitter loss), variable attenuator loss (in dB), and the measured WIAD output signal power level (in dBm within a 6 MHz bandwidth).

However, in essence, there were *two* system gains since the indoor test setup did *not* use an amplifier and long coaxial cable but rather a relatively short, low-loss cable feeding a variable attenuator followed by the CH 9 band-pass filter. The outdoor and indoor system gains were separately calibrated (and recorded) for use in their respective field strength calculations. The input attenuator also provided the means to determine the test site white noise *margin* by attenuating the received signal level to just *above* threshold of visible errors (**TOV**), as limited by the truck's broadband noise floor (outdoor tests) or the receiver's (ATSC1 or ATSC3) noise floor (indoor tests).

By initially adjusting the selected attenuator value (to provide an *approximate* -50 dBm/6 MHz signal level at the spectrum analyzer input to minimize amplifier overload), the DTV field strength was accurately calculated using the following equation:

$$\text{F.S. (dB}\mu\text{V/m)} = S - G_T + A + K - G_A \qquad \text{(Eqn 1)}$$

where **F.S.** is the electromagnetic field strength (in dBμV/m) at the antenna input

S is the measured signal level at the spectrum analyzer input (in dBm/6 MHz)

$\mathbf{G_T}$ is the total system gain (in dB) at the RF test channel *center* frequency

A is the attenuator level (in dB) that provides a signal level of about -50 dBm/6 MHz

$\mathbf{G_A}$ is the forward antenna gain (in dBd) at the RF test channel center frequency

K is the dipole conversion factor (in dBμV/m-dBm) at the test channel center frequency

The input attenuator also provided the means to determine the DTV site margin by attenuating the received signal to just *above* threshold of visible errors (**TOV**) and threshold of audible errors (**TOA**), a value that was determined by the truck's *measured* noise floor (and *corrected* for the spectrum analyzer's own measured internal noise floor) during the outdoor testing. Note that when the attenuator was increased in order to lower the desired signal to just above TOV, all the antenna signals (including the adjacent channel interfering signals) were lowered as well. Therefore, this simple method only provides test site margin with respect to white noise (as determined by the truck's amplifier) and any propagation multipath that might be present. Therefore, this is ***NOT*** a test to determine the margin (i.e., the lowest signal level) of the desired signal with respect to interfering signals (e.g., such as adjacent channel DTV signals or impulse noise).

Table 3 shows the outdoor and indoor field test receive system parameters for the RF test channel, including the theoretical dipole factors, the measured calibrated antenna gain, and the measured truck's system gain and noise floor values.

Table 3 Field test receive system parameters used in field strength and SNR calculations.

RF Test System	Receive Antenna Type	RF Test CH (#)	Antenna Gain (dBd)	Dipole Factor (dBμV/m-dBm)	System Gain[1] (dB)	System Noise Floor[2] (dBm/6 MHz)
Outdoor	DUV-S	9	2.1	+120.7	+8.6 [1]	-87.9 [2]
Indoor	DUV-I	9	-0.7	+120.7	-0.75 [3]	-99.2 [4]

[1] System gain based on outdoor receive system downlead cable loss and WIAD amplification.
[2] System gain based on indoor receive system cable loss and splitter loss.
[3] System noise floor based on outdoor system WIAD output noise floor.
[4] System noise floor based on indoor system receiver input noise floor (assumes a 7 dB receiver noise figure).

At every test site, the directional DUV-S was mounted on the truck's pneumatic mast and slowly raised to 30' AGL for the first antenna height outdoor data collection and then immediately lowered to 15' AGL for the second antenna height outdoor data collection. During indoor testing, the tripod-mounted bi-directional DUV-I was brought inside with the appropriate testing hardware as well as the ATSC1 and ATSC3 receivers for the indoor measurements.

FIELD TEST PLAN

MEASUREMENT OVERVIEW

MSW created a *customized* field test plan and data spreadsheet for this field test, and made available two experienced field test personnel (engineer and technician) to gather the data. MSW also provided measurement test equipment, a fully-equipped test vehicle capable of performing 30' AGL and 15' AGL fixed outdoor site measurements, and transportable equipment for indoor measurements. The ATSC3 exciter and receiver were provided by ETRI, the transmitter pre-corrector by TeamCast, the high-power transmitter by GatesAir, and the high power mask filter by Dielectric. MSW conducted these field measurements at **88** *outdoor* test sites on **5** radials and **2** grids throughout the metropolitan Cleveland area during the *day-time* hours (typically 8:00 am to 5:00 pm) over a **5-week** period from January 25, 2015 through February 25, 2016, inclusive.

This field test followed testing methodology used in the past, including field work performed during the Grand Alliance tests in Charlotte, NC, the Model DTV Station in Washington DC, and subsequent numerous DTV field tests performed by MSW over the last 12 years. Finally, MSW provided expert data analysis and organization, and created a written report (this document). In addition to the report, MSW also archived the Excel test data spreadsheet.

As part of the test plan, a calibrated mast-mounted directional *consumer* antenna was used to accurately measure the CH 9 DTV RF test signals (ATSC1 and ATSC3) at outdoor locations at receive antenna heights of both 30' AGL and 15' AGL. Indoor sites used a tripod-mounted bi-directional *consumer* antenna to measure these same test signals. At each test site, the receive antenna azimuth angle was adjusted for maximum CH 9 field strength. All test measurements included coverage (field strength), service (reception during a 30-second sample period), and service margin (amount of signal reduction to reach TOV, if TOV existed at all). Additionally, threshold SNR values were recorded from the ATSC3 prototype receiver from internal measurements (none were available for the consumer ATSC1 receiver).

ATSC1 performance evaluation was accomplished through watching video from the CECB unit in the truck, while ATSC3 performance evaluation was accomplished through the use of frame error rate (FER) detection in the ATSC3 receiver. This error detection was performed after the LDPC, BCH, and CRC decoding circuits in the receiver, and represented the number of *uncorrectable* data errors. No video or audio was used to determine ATSC3 threshold, just data errors.

TEST SIGNALS

The general purpose of the outdoor and indoor field tests was to compare the newly proposed ATSC3 transmission system to the current ATSC1 system using a high-VHF channel (e.g., CH 9) with its longer wavelength than those of UHF channels. Specifically, it was desired to compare and evaluate the RF performance of three different potential ATSC3 modes with that of ATSC1:

(4) Fixed reception with essentially equivalent TOV (but higher ATSC3 data rate)

(5) Fixed reception with equivalent payload rate (with slightly lower ATSC threshold)

(6) Fixed robust reception (e.g., for severe indoor conditions with very low ATSC3 threshold and much lower ATSC data rate)

The three ATSC3 transmission standard modes selected for comparison to ATSC1 are generally summarized in **Table 4** below. All three ATSC3 modes were evaluated in comparison to the ATSC1 transmission standard for both the outdoor and indoor tests.

Table 4 General ATSC3 field test signal description.

Mode Parameter	ATSC3-A	ATSC3-B	ATSC3-C
Occupied BW	5.832844 MHz	5.832844 MHz	5.832844 MHz
FFT Size	32k	32k	16k
Constellation	64-QAM (NUC)[1]	64-QAM (NUC)[1]	QPSK
FEC	11/15 LDPC[2]	10/15 LDPC[2]	5/15 LDPC[2]
Guard Interval	148.148 μsec	527.78μsec	148.148μsec
Frame Length	251.34 msec	249.63msec	251.34msec
Payload	23.1136 MB/sec	18.99234 MB/sec	3.23167MB/sec
Ideal BICM TOV[3]	14.28 dB	12.88 dB	-1.7 dB
Ideal OFDM TOV[4]	14.98 dB	13.64 dB	-0.9 dB
AWGN Lab Threshold[5]	16.04 dB	14.62 dB	+0.1 dB
Laboratory Sensitivity[6]	-85.3 dBm	-86.2 dBm	-100.25 dBm

[1] NUC means **Non-Uniform Constellation**

[2] LDPC means **Low Density Parity Code**

[3] BICM TOV means bit interleaved coded modulation threshold of visible errors (primarily inner code threshold)

[4] OFDM TOV means orthogonal frequency division multiplexing threshold of visible errors (primarily outer code threshold)

[5] As measured on CH 9 at -50 dBm in 0.1 dB steps using FEC detector after BCH decoder with FER threshold = 10^{-4}, including Rx implementation loss

[6] Minimum pristine (no impairments) ATSC3 prototype receiver input signal level @ CH 9 threshold (i.e., *direct* receiver input, with **no** external preamp)

A more detailed summary of the ATSC3 test signals can be found in **Table A3-1** in **Appendix 3**.

MEASUREMENT LOCATIONS

All **88** outdoor test sites were selected by MSW to randomly sample diverse geographical locations in the metropolitan Cleveland area on **5** radials (total of **59** sites) surrounding the Parma transmitter site and **2** grids (total of **29** sites) in urban and suburban areas.

Many of the outdoor test sites were expected to reside near or within the 36 dBµV/m theoretical noise-limited field strength contour for high-VHF ATSC1 channels and those beyond this contour to be within the threshold range of the ATSC3 robust mode. Each of the **5** radials covered **60** miles, and was named in terms of azimuth angle (e.g., 0 degrees is due north of the Parma transmitter site), and were selected prior to the start of the field test. Each of the radials had **12** test sites separated by 5 miles, except for Radial R107 which only had **11** sites due to the presence of an Ohio National Guard military base at one test site. However, the *exact* measurement test site locations were determined based on the local site logistics (e.g., available roads and parking places) at the time of the test. **Figure A3-1a** illustrates the visited *outdoor* radial test sites on a map in **Appendix 3**, which ranged in distance from the transmitter between **5** and **60** miles.

A total of **29** outdoor sites within **2** grids were selected to provide information for close-in urban reception (Cleveland) and moderate distance suburban reception (Akron). MSW selected the *general* fixed measurement locations *prior* to the start of the measurement program with the *exact* measurement test site locations determined based on the local site logistics at the time of the test. **Figure A3-1b** illustrates the visited *outdoor* grid test site locations on a map.

Indoor sites were selected to be diverse buildings (types and locations) available during the scheduled indoor testing time at various business/commercial locations. A total of **4** indoor sites were measured, varying in distance from the transmitter between **4.8**and **30.6** miles, and on various floors within a building. Like the outdoor tests, the indoor tests consisted of making two sets of measurements. However, instead of two different antenna heights above ground, the first set of data was gathered with the indoor antenna in a horizontal position to receive the *horizontal polarization* component of the received signal while the second set of data was gathered with the indoor antenna in a vertical position to receive the *vertical polarization* component of the received signal. Therefore, if there was significant signal de-polarization of the DTV signal, both components could be measured and compared. **Figure A3-1c** illustrates the visited *indoor* test site locations on a map.

The total number of outdoor field test sites (radial plus grid) visited was large enough to be meaningful, and provided both general and specific comparison information on high-VHF reception between ATSC1 and ATSC3 in a variety of receive conditions. However, the small number of indoor test sites was NOT statistically-meaningful in nature, but rather provide a handful of sites available for in-depth testing and initial high-VHF indoor reception field experience. **Table 5** summarizes the Cleveland **88** outdoor and **4** indoor test site locations.

Table 5 Outdoor and indoor fixed test site descriptions.

Group Name	# of Test Sites	Site Comments
R052	12	Northeast of Cleveland
R107	11	East of Cleveland
R154	12	Southeast of Cleveland
R225	12	Southwest of Cleveland
R270	12	West of Cleveland
Grid 1	17	Cleveland (Urban)
Grid 2	12	Akron (Suburban)
Indoor	4	Urban and Suburban
TOTAL	**92**	**Visited Test Sites**

MEASUREMENT PROCEDURES

Prior to the start of the measurement tests, the forward gain of *each* consumer receive antenna (DUV-S and DUV-I) were calibrated once at 30' AGL at a location with open space in order to minimize ground reflections. Both the directional (**DUV-S** for 30' AGL measurements) and the bi-directional (**DUV-I** for indoor measurements) antennas were measured at CH 9 against a reference half-wave VHF dipole antenna also positioned at 30' AGL for the most accurate calibration results (i.e., with minimal ground clutter/reflections). However, it should be noted that the Cleveland field test only used a horizontally-polarized transmit signal, i.e., a signal with no vertical component.

The following is a description of the test procedures for measuring ATSC1 and ATSC3 *fixed* outdoor (radials and grids) and indoor reception used in the 2016 NAB field test:

1. Plot test locations on electronic road maps prior to the start of testing to identify streets providing a reasonable match to the desired measurement test sites and objectives.
2. Plan each test day's work to achieve the maximum results with the least amount of drive time.
3. Confirm proper operation of DTV transmitter, field test truck, and/or indoor test equipment.
    a. Verify proper transmitter operation.
    b. Verify truck generator, mast, GPS, and general vehicle functionality.
    c. Verify attenuator functionality, in dB (10 dB steps and 1 dB steps), for test channel.
    d. Verify converter boxes, monitors, and remote controls operation for each test channel.
4. Calibrate truck parameters.
    a. Measure and record truck system gain, in dB (antenna output to spectrum analyzer input) for the RF test channel of the given test system.
    b. Measure and record truck noise floor, in dBm/6 MHz, for each RF test channel.
5. At each test site location, perform the following:
    a. Confirm feasibility of *safely* raising mast to 30' AGL (for outdoor tests) without encountering obstructions; otherwise, move to closest suitable location.

b. Employing GPS, determine exact coordinates of test site location, calculate the distance and bearing to the transmitter. Record these results together with a description of the test site (including a street address, if possible, and nearby cross streets), and any anomalous observations regarding the test site. Note and record weather conditions (temperature, sun, clouds, rain, fog, sleet, snow, etc.).

c. For outdoor measurements, attach the calibrated Digitenna **DUV-S** antenna to the pneumatic *mast*, connect to mast's coaxial feedline, and raise the antenna to 30' AGL.

d. For indoor measurements, attach the calibrated Digitenna **DUV-I** indoor antenna to the *tripod*, connect to its own coaxial feedline to the band-pass filter which alternately feeds the spectrum analyzer and receivers, and place tripod at an appropriate location inside the building.

e. Remotely set the test transmitter to transmit the ATSC1 signal.

f. Perform the following measurement procedures.

   i. Adjust antenna azimuth for maximum signal level by rotating the antenna.

   ii. Adjust input attenuator to achieve an RF system DTV output level of *about* -50 dBm/6 MHz, if possible. Verify and record input attenuator setting.

   iii. Accurately measure the average power in 6 MHz of the received DTV signal at the spectrum analyzer input. Note any RF signal level variations over a 30-second time period. If necessary, remotely turn off the desired signal to determine if any co-channel signals are present.

   iv. Calculate DTV rms field strength (in dBµV/m/6 MHz) using signal power (in dBm), antenna gain (in dBd), appropriate dipole factor (dBµV/m-dBm), input attenuator (in dB), and RF system gain (in dB).

   v. Calculate SNR value using signal power (in dBm/6 MHz), truck noise power (in dBm/6 MHz), and input attenuator (in dB).

   vi. Note any nearby large signals (i.e., potential interferers). Record level of any large CH 9 co-channel signals (with test transmitter turned off) or any large adjacent channel signals (e.g., CH 8 or CH 10).

   vii. Increase input attenuator in 1-dB steps until signal just ***above*** TOV (i.e., lowest signal level where no picture pixelization errors exist or where no frame errors occur), and record attenuator setting (i.e., the site margin). Note any "hits" (burst errors) from passing traffic, and record at every failed site an estimated reason for the cause of failure.

g. Remotely set the test transmitter to transmit the ATSC3 signal, and repeat the measurement procedure described in {5f} above for all three ATSC3 modes.

h. After completing the 30' AGL measurements, lower the mast to 15' AGL to make these measurements (using same procedures as in {5f} above) for all 4 test signals (i.e., ATSC1, ATSC3-A, ATSC3-B, ATSC3-C).

i. For indoor measurements, use same procedures as in {5f} above for all 4 test signals.

j. Verify that all data is properly logged and archived, and all equipment is back in its proper place, and the truck mast is completely lowered.

k. Proceed to next measurement location and repeat step 5 above.

For ATSC1 fixed site measurements, the Zenith converter unit's down-converted HDTV video output was observed on a monitor, and the last error-free attenuator setting was used to determine the threshold. ATSC3 threshold was determined by the ATSC3 receiver's frame error measurements. The values that were output by the ATSC3 receiver represented the number of errors measured by the FEC circuitry in a single data frame (either 251.34 msec window or 249.63 msec window, dependent on the transmitted transmission mode).

FIELD TEST RESULTS

GENERAL OVERVIEW

During the Cleveland DTV field test, a great deal of data was gathered. The test plan called for measuring ATSC1 and ATSC3 outdoor coverage and service reception data utilizing two different receive antenna heights above ground level at **88** outdoor test sites covering a 60-mile radius. These test sites were grouped as **5** radials and **2** grids. Likewise, reception data for **4** indoor reception sites was obtained. The *raw* data for all of the radial and grid outdoor tests is summarized in **Table A4-1** in **Appendix 4** while the overall data analysis summary is contained in **Table A4-2**.

Note that entire suite of test sites from the five radials had distances from the transmitter that varied from about **5** miles to **60** miles, with a *median* distance of **22.6** miles, therefore covering a large area of the Cleveland market. The five radials (R50/Northeast, R107/East, R154/Southeast, R225/Southwest, R270/West) each had **12** sites (except for radial R107, which only had **11** sites since one of the planned test sites (#7) was unavailable due to its location in the middle of a National Guard military base). The **2** grids were located in Cleveland (17 sites at an approximate distance of **17** miles) and Akron (12 sites at an approximate distance of about **22** miles).

Table A4-1a (30' AGL data) and **Table A4-1b** (15' AGL data) include field strength level, reception service, reception threshold SNR values, and reception margin for each test site for both a 30' AGL and 15' AGL directional consumer DUV-S receive antenna height. The data measurement parameters were all determined with the *reference* test equipment and test methodology described previously.

Table 13 (later in this section) provides similar data as described above, except the tests were performed inside a building with a bi-directional consumer DUV-I indoor antenna mounted on a 5' high tripod. The two sets of measured indoor data reflect the difference in reception and margin between a horizontally-polarized and vertically-polarized receive antenna, therefore providing information about the amount of any de-polarization (if any) that might have occurred for the horizontally-polarized transmitted signal due to non-line-of-sight propagation conditions.

The number of outdoor tests were meaningful, but the indoor tests were not. Note that all of the field testing occurred over a relatively short period of time during daytime hours (weekdays 8:00 am to 5:00 pm), and therefore the test results can't determine what the prognosis will be for DTV reception over a longer period of time (e.g., an entire day that covers diurnal effects or many months that cover seasonal effects). If needed, both location and time variability can be studied in the future for more detailed analysis, particularly for indoor reception which is by far more sensitive than outdoor reception.

OVERALL SERVICE DATA

One of the main goals of the field test was to determine absolute high-VHF CH 9 *outdoor* service values for both 30' AGL and 15' AGL for all 4 test signals (ATSC1 and 3 modes of ATSC3) throughout the Cleveland service area. By doing so, a direct comparison of service among the different transmission standards and modes can be easily observed.

Table 6 summarizes the basic *service* (i.e., error-free reception) performance measured at all **88** outdoor sites for the four test signals at both reception heights. These results provide reasonable performance trends. The data is broken down into 30' AGL and 15' AGL reception conditions as well as the total of the two different antenna heights.

Table 6 Overall outdoor DTV *service* results.

Receive Antenna Height AGL	ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites
30' AGL	73	88	83.0	62	88	70.5	66	88	75.0	84	88	95.5
15' AGL	67	88	76.1	55	88	62.5	59	88	67.0	79	88	89.8
Totals	140	176	79.5	117	176	66.5	125	175	71.0	163	176	92.6

Note: All **88** outdoor test sites are represented in this table.

In absolute terms, the success rates are very reasonable with 70% or better at a 30' AGL receive antenna height, and 62% or better at a 15' AGL height. These success rates should be viewed in light of the fact that the transmitted signal had an ERP of only 10 kW and it was emanating from a relatively low side-mounted antenna over a 60-mile radius area, and in an area where co-channel signals existed that sometimes reduced the success rate.

The two ATSC3 modes that had relatively high data rates (ATSC3-A and ATSC3-B) had slightly lower success rates than ATSC1. It should be noted that the higher data rate (23.1 Mbps) ATSC3-A mode that attempted to duplicate the 14.9 dB ATSC1 threshold actually had a 1.2 dB *higher* (i.e., worse) white noise threshold than ATSC1 while the comparable data rate (19.0 Mbps) ATSC3-B mode had a slightly lower 14.1 dB noise threshold. Part of the problem was the use of a less robust high-VHF tuner for the ATSC3 prototype receiver that was affected by the dual first adjacent channel interference present in this field test. Despite this, comparable service was achieved for both the 30' AGL and 15' AGL antenna height outdoor tests.

MSW engineers found very few test sites (2 at 30' AGL and 3 at 15' AGL conditions) where impulse noise was a limiting factor for outdoor reception. This has been observed in some of the past ATSC1 VHF field tests, such as close proximity of the mast-mounted receive antenna to high-tension power lines (especially with dirty insulators that tend to arc) or pole-mounted step-down transformers. It is more likely to find impulse noise *inside* private homes, and even then it has been found in past field tests that impulse noise is not the primary limitation, but rather broadband noise radiating out of digital consumer devices such as DTV sets, digital CATV converter boxes, VCRs, DVDs, DVRs, telephones, etc. that have become ubiquitous over the last 10 years. To determine ATSC1 and ATSC3 performance in these environments would require doing a large number of actual in-home testing at some time in the future.

OVERALL COVERAGE AND MARGIN DATA

Table 7 summarizes basic *coverage* and *reception margin* comparison results measured at all **88** outdoor test sites for the 4 test signals at both 30' AGL and 15' AGL receive antenna heights. Coverage represents the CH 9 signal levels measured at the outdoor test sites while margin represents the amount of signal reduction that can occur at the receiver before threshold is reached (note: margin measured by attenuating the signal in the field test truck also reduces any interference or impulse noise signals, and therefore this method only represents a margin performance value for white noise and signal impairments).

While signal strength at the receiver for a given site should ideally be equal for all 4 test signals (same high power transmitter, transmit antenna, receive antenna, receive distribution system, etc.), it should be noted that slight differences existed at each site. This is due to the switch between two different exciters for ATSC1 and ATSC3 (adjusted to be *approximately* the same value) as well as the fact that the received signal levels were measured at slightly different times during the sequential testing of these various signals (i.e., possible variations exist due to signal "breathing"). It should be noted that statistical margin calculations were made by ignoring all of the sites with no margin (i.e., no reception), and only considering margins at sites that had error-free reception.

Table 7 Overall outdoor DTV *signal coverage* and *reception margin* results.

Receive Antenna Height AGL	ATSC1		ATSC3-A		ATSC3-B		ATSC3-C	
	Median FS (dBµV/m	Median Margin (dB)	Median FS (dBµV/m	Median Margin (dB)	Median FS (dBµV/m	Median Margin (dB)	Median FS (dBµV/m	Median Margin (dB)
30' AGL	63.0	28.0	63.3	29.5	63.2	29.5	63.2	41.0
15' AGL	58.3	25.0	58.1	24.0	58.2	26.0	58.2	39.0
30' – 15' AGL	4.7	3.0	5.2	5.5	5.0	3.5	5.0	2.0

Note: All **88** outdoor test sites are represented in this table.

The data reflects *both* close-in and far-out test sites, yet it indicates for each test signal comparable field strength results, with good signal strength over large distances and diverse transmit antenna azimuth angles for both 30' AGL (median value of ≈ **63** dBµV/m) and 15' AGL (median value of ≈ **58** dBµV/m) reception. Likewise, the margin values at 30' AGL for all 4 test signals (range between **28** dB and **41** dB) show the differences between the ATSC1 system and the ATSC3 system, providing assurance that ATSC3 outdoor reception with a roof or attic antenna should be straightforward.

While the 15' AGL median *margin* values are also good (range between **24** dB and **39** dB), they reflect a slightly lower median margins (**2.0** dB to **5.5** dB) than the 30' AGL values due to the typically reduced signal strength that occurs at lower receive antenna heights. However, the data at both receive antenna heights reflects that there is significant margin that would allow reasonable outdoor reception. The consideration of 15' AGL receive antenna heights in addition to the traditional 30' AGL height value (from the late 1950s) has become important over the last 20 years as the majority of homes typically are not high easily enough to support 30' AGL (e.g., ranch style houses or even raised ranch houses) without the use a very tall tower. Therefore, good results at the lower 15' AGL height with only several dB of loss in signal level and margin is important in moving forward with over-the-air broadcasting, especially when considering transmitter ERP values during the repack.

Finally, field strength versus margin evaluation was performed using all of the test site data for each of the 4 test signals at two different receive antenna heights in order to determine how well the service margin can be predicted by measuring field strength. In the early days of DTV (late 1990s) when early-generation ATSC1 receivers were used, margin was not only affected by signal strength but was also considerably affected by the presence of moderate multipath. This was due to the fact that many of the early ATSC1 receivers did not have robust channel equalizers (i.e., multipath cancellers), and therefore either significantly degraded the 15-dB SNR white noise threshold or just caused reception failure.

In recent years (5th generation and later), the equalizers got longer, faster, and more robust, which allowed significantly improved reception and reduced white noise threshold degradation in the presence of significant multipath. While severe multipath can still affect reception margin, it now has a diminished effect in modern ATSC1 receivers. With the ATSC3 system that utilizes COFDM and far more advanced FEC, multipath effects should be even less significant in most cases, even in non-line-of-sight locations that experience severe multipath as well as low-level signals. Therefore, margin analysis comparing the two transmission standards is beneficial.

In this analysis, the data from all of the outdoor test sites is sorted for *each* of the 4 test signals according to decreasing values of field strength (in dBµV/m), paired with their measured site margin (in dB), and then plotted on a linear dB scale (both x-axis field strength and y-axis margin). In doing so, the theoretical margin response should be a decreasing straight line, dB for dB, i.e., for every 1-dB reduction in signal strength, there should be a corresponding 1-dB decrease in service margin. Ideally, any variation from a dB-for-dB straight line besides that due to slight measurement errors or signal level variation during the measurement time interval is typically in the direction of reduced margin. This variation can also be due to additional factors such as multipath, DTV-DTV interference, man-made noise, natural-occurring impulse noise (on VHF), or FM radio interference (on VHF channels, such as CH 9). Therefore, this type of analysis plot can provide some insight into DTV reception in a given market for a particular RF channel.

Figure A4-1a though **Figure A4-1h** contains the field strength versus margin plots for each of the 4 test signals. The lines for the 30' AGL measurements for *each* test signal are fairly straight, with minimal variation from the linearly decreasing characteristic. However, the 15' AGL lines have more variation for the ATSC1 signal because of the increased variation in signal level at lower receive antenna heights as well as the increased chance of dynamic multipath due to the close proximity to the ground. Note that the point where the decreasing margin line crosses the x-axis (i.e., at zero margin which indicates site failure) is the minimum signal field strength level for that test signal mode.

THRESHOLD PERFORMANCE

Another important parameter of interest regarding DTV reception is the actual TOV thresholds of the two transmission systems measured in the field. The *theoretical* (i.e., an ideal, unimpaired desired signal) additive white Gaussian noise threshold for each mode was known from computer simulation while the actual receiver *hardware* threshold (with implementation error margin) was obtained from laboratory measurements that also used unimpaired desired signals (see **Table 2**). However, knowledge of field threshold performance is desired where non-ideal (i.e., impaired) signals are received at the viewer's premise.

Table 8 shows the threshold results measured in the Cleveland field test at all **88** outdoor test sites, along with the internal ATSC3 receiver SNR measurement values recorded at each threshold. Note that since a consumer ATSC1 receiver (CECB unit) was used in this field test, no internal receiver SNR values were available to record for this legacy unit.

Table 8 Overall outdoor DTV *threshold* SNR results[1].

Receive Antenna Height AGL	ATSC1 Median Rx SNR[2] (dB)	ATSC3-A Median Rx SNR3[2] (dB)	ATSC3-B Median Rx SNR[2] (dB)	ATSC3-C Median Rx SNR[2] (dB)
30’ AGL	-----	16.0	14.5	-0.6
15’ AGL	-----	16.1	14.6	-0.6
30’ – 15’ AGL	-----	-0.1	+0.1	0.0

Note 1: All **88** test sites are represented in this table.
Note 2: Rx SNR is the internal ATSC3 receiver hardware SNR measurement (ATSC1 receiver had no such internal SNR reading).

Note that the median values of ATSC3 receiver threshold SNR values were reasonably similar (within 0.5 dB) to the laboratory white noise thresholds, thus indicating that multipath effects did not have a significant effect on site reception thresholds across the entire field test area. The data above also demonstrates that most of the reduction in median margin described in the previous section (2.0 to 3.5 dB) with respect to receive antenna height was due to signal level reduction rather than multipath threshold enhancement effects.

PERFORMANCE VERSUS DISTANCE

The overall outdoor service results from all **88** test sites was grouped in *five-mile* increments for both the 30’ AGL height and 15’ AGL height are shown in **Table 9a** and **Table 9b**, respectively. All test sites are included (i.e., radials and grids), and cover the 60-mile radius described in the field test plan.

Table 9a Distance performance results of 30’ AGL for all 4 test signals.

	ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
Site Distance (miles)	Med FS (dBµV/m)	Med Margin (dB)	% Good Sites	Med FS (dBµV/m)	Med Margin (dB)	% Good Sites	Med FS (dBµV/m)	Med Margin (dB)	% Good Sites	Med FS (dBµV/m)	Med Margin (dB)	% Good Sites
2.5 - 7.5	89.9	52.0	100.0	89.9	53.5	80.0	90.0	53.0	100.0	89.9	67.0	100.0
7.5 - 12.5	76.0	38.5	100.0	76.2	40.0	77.3	76.2	40.0	77.3	76.2	53.5	100.0
12.5 - 17.5	70.4	32.0	100.0	70.4	32.0	100.0	70.3	33.0	100.0	70.4	48.0	100.0
17.5 - 22.5	63.5	25.5	100.0	63.4	25.0	75.0	63.4	27.0	83.3	63.5	41.0	100.0
22.5 - 27.5	63.7	26.0	100.0	63.7	26.5	80.0	63.6	26.5	100.0	63.7	41.0	100.0
27.5 - 32.5	73.0	35.0	100.0	73.0	35.0	100.0	73.1	36.0	100.0	73.1	51.0	100.0
32.5 - 37.5	58.5	26.0	50.0	58.5	25.5	50.0	58.5	27.0	50.0	58.3	36.0	100.0
37.5 - 42.5	51.9	14.0	80.0	52.1	13.0	80.0	52.2	15.0	80.0	52.1	30.0	100.0
42.5 - 47.5	44.3	18.5	40.0	44.6	17.5	40.0	44.6	19.0	40.0	44.6	24.5	80.0
47.5 - 52.5	46.3	15.0	40.0	46.3	14.0	40.0	46.3	16.0	40.0	46.4	25.0	80.0
52.5 - 57.5	42.4	14.5	40.0	43.0	14.0	40.0	43.1	15.0	40.0	43.1	14.0	100.0
57.5 - 62.5	41.4	7.0	40.0	41.6	6.0	40.0	41.6	7.0	40.0	41.4	19.0	60.0
Median	**63.0**	**28.0**	**83.0**	**63.3**	**29.5**	**70.5**	**63.2**	**29.5**	**75.0**	**63.2**	**41.0**	**95.5**

Table 9b Distance performance results of 15’ AGL for all 4 test signals.

Site Distance (miles)	ATSC1 Med FS (dBµV/m)	ATSC1 Med Margin (dB)	ATSC1 % Good Sites	ATSC3-A Med FS (dBµV/m)	ATSC3-A Med Margin (dB)	ATSC3-A % Good Sites	ATSC3-B Med FS (dBµV/m)	ATSC3-B Med Margin (dB)	ATSC3-B % Good Sites	ATSC3-C Med FS (dBµV/m)	ATSC3-C Med Margin (dB)	ATSC3-C % Good Sites
2.5 - 7.5	88.6	51.0	100.0	88.4	51.0	80.0	88.4	52.0	80.0	88.5	66.0	100.0
7.5 - 12.5	68.8	33.5	90.9	68.8	36.0	63.6	68.9	36.5	72.7	68.8	46.5	100.0
12.5 - 17.5	67.3	29.0	100.0	67.3	30.0	80.0	67.2	30.0	100.0	67.4	45.0	100.0
17.5 - 22.5	59.9	23.0	91.7	60.3	23.0	75.0	60.3	24.0	75.0	60.3	38.0	100.0
22.5 - 27.5	56.0	17.0	90.0	56.0	18.5	80.0	56.0	19.0	90.0	56.0	33.5	100.0
27.5 - 32.5	68.4	30.0	100.0	68.4	31.5	80.0	68.4	33.0	80.0	68.2	46.0	100.0
32.5 - 37.5	54.1	23.0	50.0	54.2	22.0	50.0	54.2	24.0	50.0	54.2	33.0	75.0
37.5 - 42.5	47.0	13.0	60.0	47.1	12.0	60.0	46.9	14.0	60.0	47.1	26.0	80.0
42.5 - 47.5	42.9	13.0	40.0	42.4	12.0	40.0	42.4	13.0	40.0	42.4	19.5	80.0
47.5 - 52.5	42.9	6.0	40.0	42.9	5.0	40.0	42.9	7.0	40.0	42.9	22.0	60.0
52.5 - 57.5	40.5	6.5	40.0	41.6	5.5	40.0	41.6	7.0	40.0	41.6	14.5	80.0
57.5 - 62.5	35.5	6.0	20.0	35.5	5.0	20.0	35.7	6.0	20.0	35.7	17.5	40.0
Median	**58.3**	**25.0**	**76.1**	**58.1**	**24.0**	**62.5**	**58.2**	**26.0**	**67.0**	**58.2**	**39.0**	**89.8**

With some exceptions, the field strength and margin values decrease with increased distance and lower receive antenna heights. The exceptions can be typically caused by differences in terrain and local propagation “clutter” as well as the fact that some distance groups only have 4 or 5 samples in them and therefore do not provide good statistical results.

Nevertheless, the ATSC3-A and ATSC3-B test signal margins are essentially the same or slightly worse than ATSC1 since their threshold margins are somewhat comparable. The robust ATSC3-C test signal margin is significantly better than all of the others. As discussed previously, better numbers would have been achieved without the adjacent channel interference effects on the fragile ATSC3 receiver.

SYSTEM PERFORMANCE INDEX

The data analysis above reflects absolute coverage, service, margin, and threshold results for all of the outdoor test sites. For commercial broadcasters, knowledge of the absolute performance numbers for coverage and service of *all* **88** outdoor test sites in their designated market area (DMA) is not only desirable but critical since it gives an indication of the number of potential viewers that can be reached. Also when comparing two transmission systems (e.g., ATSC1 and ATSC3), absolute comparison of *all* test sites can show relative service performance over a large DMA.

However, an additional parameter is also helpful that describes system performance only when there is enough signal level to be received error free. That is, it is desired to know the System Performance Index (**SPI**) of the system which describes reception performance for *only* those test sites where the received signal is above the ideal minimum signal level required for error-free reception for a given transmission standard or transmission mode. These minimum signal levels for each of the four test signals are listed in **Table 2** in the “*Field Test Vehicle Description*” section of this report.

In other words, it is well understood that no reception for any transmission system is expected at sites where the received signal level is below the minimum signal level required for error-free reception, and therefore these particular failed sites should not be “counted against” the system as failed system performance. Consequently, it is beneficial to understand the percentage of sites with excess signal strength that had error-free reception, thus indicating how well the transmission system worked in various environments (such as co-channel interference) with impaired desired signals (e.g., multipath) above the minimum signal level. **Table 10** shows the SPI results for all 4 test signals.

Table 10 Outdoor DTV Service Performance Index results.

Receive Antenna Height	ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites	# Good Sites	# Total Sites	% Good Sites
30' AGL	73	80	91.3	62	79	78.5	66	80	82.5	84	88	95.5
15' AGL	67	78	85.9	55	78	70.5	59	78	75.6	79	88	89.8
Totals	140	158	88.6	117	157	74.5	125	158	79.1	163	176	92.6

Note: Only sites with signal levels above the theoretical minimum value for a given transmission mode are considered.

The ATSC3 receiver was a prototype unit with approximately 1 dB implementation error. Additionally, co-channel and adjacent channel interference existed at a number of sites that limited reception, especially for the ATSC3 receiver with a fragile front-end tuner. It is expected that optimized consumer receivers in the future will have improved RF overload performance, just as ATSC1 receivers had very significant performance improvement over time.

FAILURE ANALYSIS

The performance of the ATSC3 system did well in the field, but not quite as well as the current ATSC1 system. Therefore, a closer look at the data results, particularly those of the failed test sites, is warranted to better understand the dynamics of the test.

Failure analysis is a method that identifies trends in the causes of reception failure, often focusing on specific failure mechanisms in particular. For this NAB field test, impulse noise was one area of interest, even though the primary focus of the test was on outdoor testing where impulse noise is not as likely to be found as *inside* viewer homes and commercial establishments. The comparison between ATSC1 (8-VSB) and ATSC3 (COFDM) transmission is important since the two modulation schemes react differently in the presence of impulse noise.

However, another important aspect became apparent during the field test, and that was the ATSC3 high-VHF tuner's sensitivity to adjacent channel interference. This was due to the fact that in Korea, the high-VHF band is *not* used for television broadcasting. Therefore, a "makeshift" tuner was quickly created for this field test. It was determined by a brief laboratory-style test that the first upper and lower adjacent channel interference threshold D/U values were limited to approximately -12 to -15 dB instead of the FCC's planning factor value of -27 dB. Therefore, the presence of CH 8 and CH 10 interference signals in the field very likely caused loss of reception to the ATSC3 receiver at certain sites since there were a number of test sites where the interference threshold D/U ratios were worse than -12 dB.

Failure analysis was performed by noting the comments of the test engineers in the field test truck who observed and measured the signal levels at each test site. As a matter of typical field measurement procedure, a failure identification number was recorded at *every failed site* that indicated the estimated caused of reception failure. Additional comments were also recorded. From this information, the failed sites that experienced significant (-12 dB or worse) adjacent channel signal levels were identified, compared to the ATSC1 receiver performance, and, if ATSC1 receiver was error-free, these failed ATSC3 sites were counted as candidates for a possible failure reversal (i.e., from failed site to successful site). **Figure A3-d** displays these interference sites on a map (dark blue circles represent co-channel interference and purple triangles represent adjacent channel interference). **Table 11** contains a summary of the failure analysis results for DTV service.

Table 11 ATSC3 service failure analysis results.

DTV Test Signals	DTV Test Signals	Good/Total Test Sites	Current Reception %	*Possible* Increase of Good Sites	*Possible* Good/Total Test Sites	*Possible* New %
30' AGL	ATSC1	73 / 88	83.0	---	-------	83.0
	ATSC3-A	62 / 88	70.5	5	67 / 88	76.1
	ATSC3-B	66 / 88	75.0	4	70 / 88	79.5
	ATSC3-C	84 / 88	95.5	0	84 / 88	95.5
15' AGL	ATSC1	67 / 88	76.1	---	-------	76.1
	ATSC3-A	55 / 88	62.5	7	62 / 88	70.5
	ATSC3-B	59 / 88	67.0	7	66 / 88	75.0
	ATSC3-C	79 / 88	89.8	0	79 / 88	89.8

From these results, the ATSC3 prototype receiver performance is much closer to the mature ATSC1 consumer receiver. Also note that while the ATSC3-A signal was supposed to have an almost identical white noise threshold SNR value as the ATSC1 receiver, it actually was worse (i.e., higher) by 1.2 dB. However, no test sites were found where ATSC1 reception existed, ATSC3 did not, and the signal level fell within this 1.2 dB window. Also, it is clear from the above data that the low-data-rate robust ATSC3 mode was not helped by this analysis since there was no indication that adjacent channel interference caused failed reception.

While the above analysis indicates the number of test sites where ATSC3 reception *may* have failed due to adjacent channel interference, it is understood that the only way to know for certain would be to repeat the test at some time in the future with a more robust front-end ATSC3 tuner.

INDOOR PERFORMANCE

The test plan called for performing *anecdotal* indoor field testing, visiting as many sites as time would allow at the end of the project. With limited amount of time left after the outdoor testing was completed, **4** indoor test sites were visited, which are illustrated on the map in **Figure A3-1c**. The purpose of the indoor testing was to obtain a "flavor" of indoor reception performance differences between the ATSC1 and ATSC3 systems, particularly as consumers would experience in their homes.

Similar to the outdoor tests, two separate measurements were made during the indoor tests. However, rather than different receive antenna heights above ground level, two sets of data were obtained by using a horizontally-polarized receive antenna for one set of data, and a vertically-polarized receive antenna for the other set.

However, due to lack of time, only commercial establishments were visited as shown in **Table 12**.

Table 12 Indoor test site description.

Test Site	Location	Comments
H001	WJW Studio Garage	Near garage door on 1st floor; 12 miles
H002	Telos Conference room	Interior of building; on 2nd floor with a window; 3' gap to next building; 5.1 miles
H003	Cleveland Arcade	5-story mall-like structure, old building; 1st floor, facing away from Tx; 4.8 miles
H004	WJW Akron News Bureau	Deep basement; 30 miles

Note that these sites were *not* selected for their ease of reception at all, but rather for their challenging attributes as well as their immediate availability for testing. Three Cleveland sites varied from **4.8** miles to 12 miles from the Parma transmitter, while the one Akron test site was **30** miles from the transmitter. **Table 13** contains pertinent indoor reception data for the 4 test signals at *each* of the **4** indoor test sites.

Table 13a Indoor performance results using *horizontally*-polarized receive antenna for all 4 test signals.

Test Site	ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
	FS (dBµV/m)	Site Margin (dB)	Good or Bad	FS (dBµV/m)	Margin (dB)	Good or Bad	FS (dBµV/m)	Site Margin (dB)	Good or Bad	FS (dBµV/m)	Site Margin (dB)	Good or Bad
H001	46.0	15	GOOD	46.1	0	Bad	45.7	17	GOOD	42.7	32	GOOD
H002	29.5	0	Bad	30.4	0	Bad	30.4	0	Bad	30.2	17	GOOD
H003	54.1	0	Bad	50.9	0	Bad	50.9	0	Bad	51.1	40	GOOD
H004	36.4	0	Bad	36.4	0	Bad	36.4	0	Bad	36.4	26	GOOD

Table 13b Indoor performance results using *vertically*-polarized receive antenna for all 4 test signals.

Test Site	ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
	FS (dBµV/m)	Site Margin (dB)	THR SNR (dB)	FS (dBµV/m)	Margin (dB)	THR SNR (dB)	FS (dBµV/m)	Site Margin (dB)	THR SNR (dB)	FS (dBµV/m)	Site Margin (dB)	THR SNR (dB)
H001	43.8	0	Bad	42.2	0	Bad	44.4	0	Bad	44.6	32	GOOD
H002	27.7	0	Bad	27.6	0	Bad	27.6	0	Bad	27.6	0	Bad
H003	50.1	0	Bad	50.1	0	Bad	50.1	0	Bad	50.1	0	Bad
H004	35.5	0	Bad	35.5	0	Bad	35.5	0	Bad	35.5	0	Bad

The anecdotal results of the four indoor test sites show that the primary reception problem, particularly for the higher data rate modes at the last 3 sites, was signal strength. However, at indoor site H003 there was enough signal strength for reception, but MSW field test engineers reported significant multipath and co-channel present that limited reception. This test demonstrates that the lower-data rate robust ATSC3 mode was able to be consistently received using a horizontally-polarized receive antenna (i.e., the same polarization as the transmitted signal) in these harsh environments, even with a relatively low transmitter ERP value from a lower side-mounted antenna.

Another anecdotal result of this field test was that the signals received indoor had little de-polarization at these particular indoor test sites as signal levels were low and the main reason for limited reception. However, as with any type of reception, particularly indoor reception, transmitting a vertical polarization component (e.g., elliptical or full circular polarization) would increase the probability of reception as would the obvious case of increasing the overall transmitted ERP beyond 10 kW (e.g., to 40 or 50 kW).

LDM PERFORMANCE

Just prior to the official start of the NAB field test in Cleveland, ETRI performed a separate high-VHF test using the Layered Division Multiplex (**LDM**) mode that is available in the ATSC3 standard. The test, which included both fixed and mobile evaluation, was performed by ETRI personnel using the prototype ETRI modulator/TeamCast corrector and receiver. MSW and NAB engineers and equipment assisted in the test that lasted a couple of days.

ETRI collected the data, analyzed it, and reported on it. A brief summary of their LDM test results is located in **Appendix 5**.

SUMMARY

The **5**-week **NAB** DTV field test was performed from January 25, 2016 through February 25, 2016, inclusive, throughout the Cleveland, Ohio metropolitan market. The main purpose of the test was to compare high-VHF field performance of the proposed ATSC3 system to that of the current ATSC1 system.

The **88** fixed outdoor test sites were located on **5** radials and **2** grids, ranging from about **5** miles to **60** miles from the transmitter site that employed WJW's side-mounted high-VHF backup antenna located in Parma, Ohio. The outdoor test used a small directional receive consumer antenna that was raised to two different heights (30' AGL and 15' AGL) for data gathering. The anecdotal **4** fixed indoor test sites were selected from available locations around the Cleveland area, and used a bi-directional dipole-like indoor antenna mounted on a tripod in two different polarization positions (horizontal and vertical).

Some *general* observations and trends can be summarized from this DTV field test:

1) FIELD TEST IMPLEMENTATION:

    a. The outdoor field test was a *location* variability test. With **88** test sites, it was meaningful due to the number of measurement samples. However, it was ***not*** a time variability test since each site was visited for a short period of time, and therefore did not provide information about longer-term reception (diurnal effects) or much longer-term reception (seasonal effects).

    b. The field test transmitter sequentially radiated ≈**10 kW** ERP ATSC1 and ATSC3 signals on high-VHF CH9 from a side-mounted backup transmit antenna at a relatively low height above ground compared to two first adjacent ATSC1 commercial transmitter signals. Overall, this configuration was acceptable in most cases. However, it did allow for potential ***first adjacent channel interference*** from CH 8 and CH 10 to occur at some test sites due to the less robust ATSC3 prototype receiver's front-end tuner. Likewise, with no CH 9 allocation in the Cleveland market due to relatively nearby other CH 9 signals, use of this particular channel in the field test (particularly east and south of Cleveland) allowed for ***co-channel interference*** that affected both ATSC1 and ATSC3 reception.

    c. High-VHF reception performance of a mature design consumer ATSC1 receiver was compared to that of an early ATSC3 prototype receiver that had a non-robust front-end tuner. The lack of overload robustness against adjacent channel interference (e.g., having a measured threshold D/U worse than -12 dB instead of better than -27 dB) likely degraded ATSC3 reception performance compared with ATSC1 at a number of test sites.

2) ATSC3 SYSTEM PERFORMANCE:

a. When both outdoor receive antenna heights are considered, the two higher data rate ATSC3 signals (ATSC3-A and ATSC3-B) had slightly *lower* overall successful **service rates** (by 13 % and 8 %, respectively) than ATSC1. However, the low-data-rate robust ATSC3 signal had the best overall service rate by far, surpassing ATSC1 reception by 13% that included sites 60 miles from the transmitter. From laboratory receiver hardware measurements, the ATSC3-A signal was found to have a 1.2 dB higher (worse) threshold while the ATSC3-B signal had a 0.6 dB lower (better) threshold than ATSC1. This, along with the ATSC3 receiver front-end robustness issue, explains these field test service results. However, failure analysis showed that the ATSC3-A and ATSC3-B service numbers *likely* would have improved by 5% to 8% if a more robust ATSC3 tuner were used at test sites with significant adjacent channel interference.

b. Similarly, outdoor reception **margins** for the two higher data rate ATSC3 signals were comparable to the ATSC1 signal at both receive antenna heights. For all the test sites that had reception, the measured margin essentially decreased dB per dB with field strength according to theory, and typically did so with increasing distance for the most part. This indicates that multipath or impulse noise did not significantly affect reception in this test.

c. The ATSC3 **system performance index** (i.e., considering only sites with signal levels above the threshold required for error-free reception) was deemed to be good, with over 75% for the two higher-data rate modes (ATSC3-A and ATSC3-B) and over 95% for the low-data-rate robust mode. The two higher data rate modes would have been even greater with a more robust front-end ATSC3 tuner to combat adjacent channel interference.

d. The ATSC3 receiver's internally-measured outdoor reception **threshold SNR** values that were recorded in the field were within 0.5 dB of the laboratory-measured values, thus showing good field predictability based on laboratory measurements. These threshold values were essentially identical for both the 30' AGL and 15' AGL receive antenna heights, indicating that any measured decreased signal strength (≈5 dB), increased multipath, or increased interference (e.g., ATSC1 signals, impulse noise, etc.) had little effect on the ATSC3 system's threshold performance.

e. Indoor performance evaluation was anecdotal since only 4 test sites were visited, Only one site had enough signal level for reception of most of the 4 test signals. However, successful reception was achieved at all 4 test sites for the robust ATSC3 mode, indicating that indoor reception of these signals is very likely in many field circumstances.

f. The LDM fixed and mobile field test results are shown in the ETRI report that is contained in **Appendix 5**.

Considering all of these factors, the newly proposed ATSC3 system performed well at high-VHF frequencies, and therefore provides encouragement for its use in this frequency band. However, more laboratory and field testing, particularly if an ATSC3 receiver with a more robust front-end tuner were available and employed, would be beneficial in order to provide more insight into its performance.

ACKNOWLEDGEMENTS

As with any challenging task, many individuals are typically involved. This field test was no different. The following individuals from various companies were involved in the planning, implementation, and data analysis of the 2016 NAB Cleveland DTV field test.

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CRC: Yiyan Wu

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TeamCast: Gilles Toquet, Gerard Faria, Eric Pinson

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WJW: Jim Baird, Robert Chappell, John Cifani

GatesAir: Joe Seccia, Rich Redmond, Jay Adrick

Dielectric: Keith Pelletier, Dan Fallon, Andy Whiteside

FOX: Winston Caldwell

MSW: Dennis Wallace, Gary Sgrignoli, David Meintel

Additionally, a special thank you is extended to WTOV (Sinclair Broadcasting), WOIO (Raycom Media), and CBET (Canadian Broadcasting Company) for allowing the field test to be performed on CH 9 in the Cleveland area, and accepting limited interference during the test period.
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APPENDIX 1 DTV Transmitter Site Documentation

Table A1-1 Summary of WJW Cleveland field test transmitter site details.

Information	Parameter	NAB	WJW	WOIO	Units
General	Network	*	FOX	CBS	*
	Virtual Channel	*	8	19	*
	Physical Channel	9	8	10	*
	Frequency	186 - 192	180 - 186	192 - 198	MHz
	Wavelength	5.2	5.4	5.0	feet
	DTV TSID	*	2257	2301	*
	Facility ID	*	73150	39746	*
Tower Location	Location (latitude) Location (longitude)	41-21-48 81-42-57	41-21-48 81-42-57	41-23-15 81-41-43	* *
	Location	Parma, OH	Parma, OH	Parma, OH	*
Transmitter	Manufacturer	GatesAir	LARCAN	-----	*
	Model #	VAX3D-24	DTT-4M	-----	*
	ATSC1 Exciter	Flexiva	LARCAN	-----	*
	ATSC3 Exciter [1]	ETRI/TeamCast	-----	-----	*
	Technology	Solid State	Solid State	-----	*
	TPO	4.0	1.07	4.02	kWatts, average
Mask Filter	Manufacturer	Dielectric	ERI	-----	*
	Model #	11000014802	ENG6267WJW-TV	-----	*
Feedline	Type	3-1/8” Coaxial	6-1/8” Coaxial	-----	*
	Feedline Impedance	50	50	-----	Ohms
Antenna	Manufacturer	Harris	Andrews	Harris	*
	Antenna ID	-----	85193	108497	*
	Model #	TAB-3H	ATW12V2-HTO-8	TAC-4HB-3/12	*
	Type	3-Bay Batwing	Traveling Wave	-----	*
	Impedance	50	50	-----	Ohms
	Pattern	Non-Directional	Non-Directional	Directional	*
	Azimuth Max Gain Direction	-----	-----	168	degrees
	Beam Tilt	0.5	0.5	0.5	degrees
	Horizontal Plane Max Gain	5.1 dB	-----	-----	
	Polarization	H-POL	H-POL	H-POL	*
	Radiation Center Height	179.0 / 587.1	255 / 836.4	293 / 961	meters/feet, AGL
	Height Above Average Terrain	266.0 / 872.5	342.0 / 1121.8	304 / 997.1	meters/feet
	ERP (H-POL)	10.0	11.0	9.5	kW
	Location	Side Mount	Top Mount	-----	*
Performance	SNR/MER (ATSC1 & ATSC3)	> +30	> +30	-----	dB
	Splatter 1^{st} 500 kHz sub-band	< -52	< -47	-----	dB_{DTV}

Note 1: The CH 9 ATSC3 exciter was a prototype ETRI modulator device used in conjunction with a TeamCast upconverter/corrector.

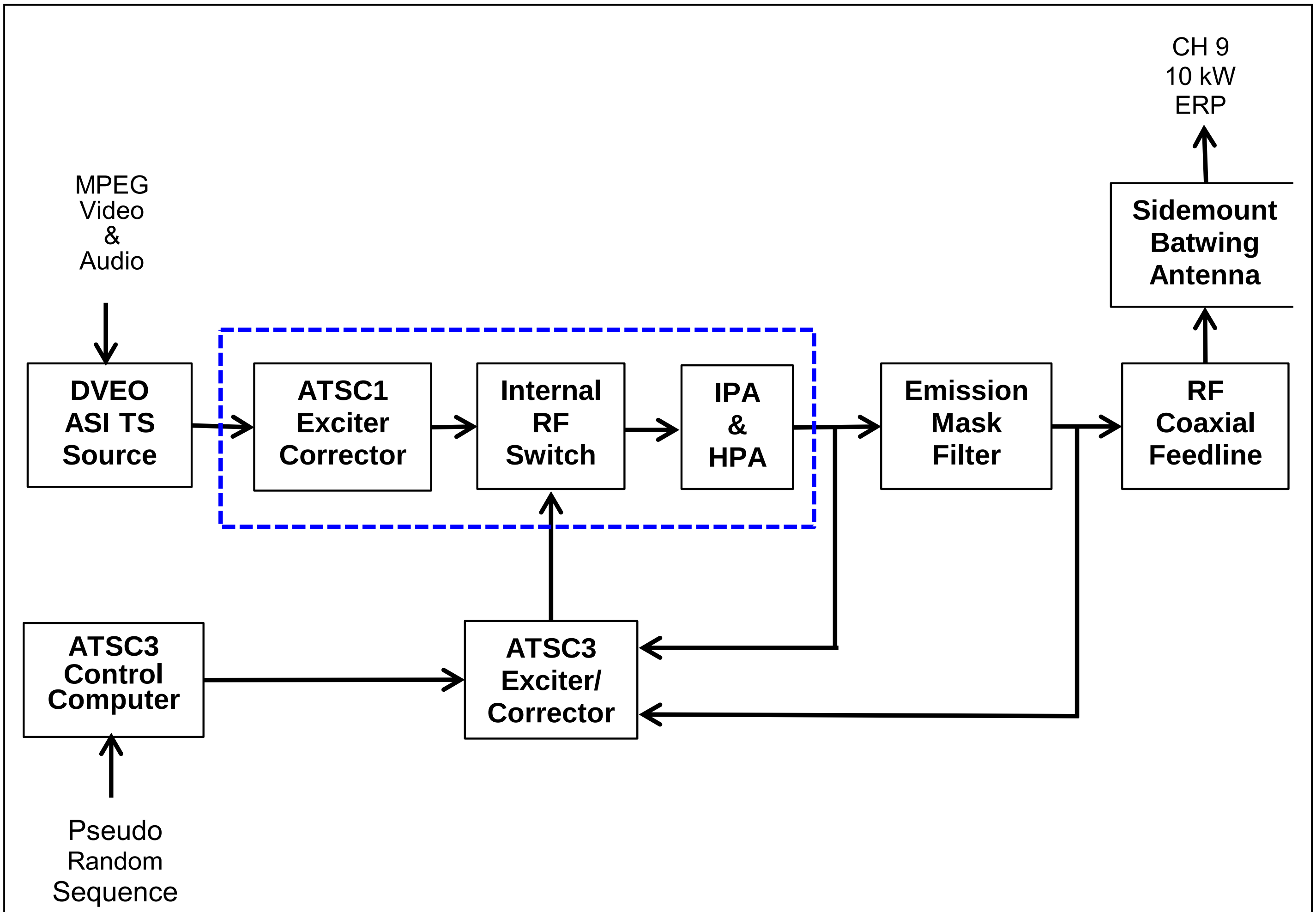


Figure A1-1 NAB CH 9 Cleveland field test transmitter block diagram.

Figure A1-2a CH 8 WJW transmitter.

Figure A1-2b CH 8 WJW mask filter.

Figure A1-3a CH 9 NAB transmitter.

Figure A1-3b CH 9 WJW mask filter.

Figure A1-4 Close-up of CH 9 GatesAir transmitter

Figure A1-5 ETRI ATSC1 exciter and TeamCast corrector with control computers for each unit.

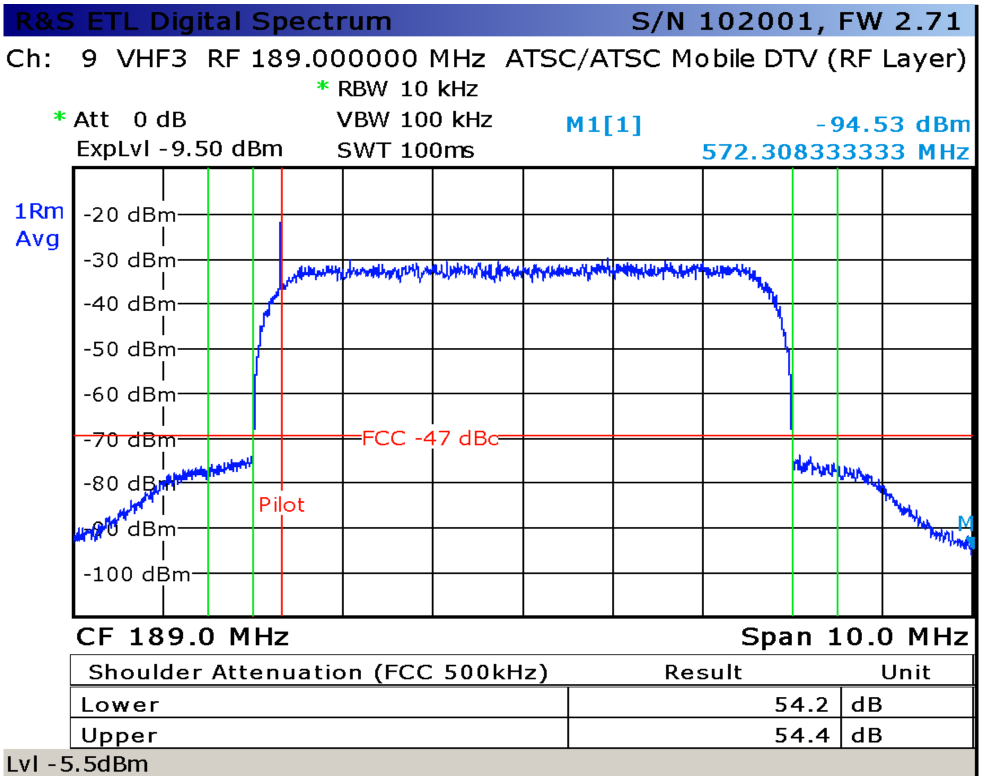


Figure A1-6a NAB CH 9 ATSC1 transmitter spectrum.

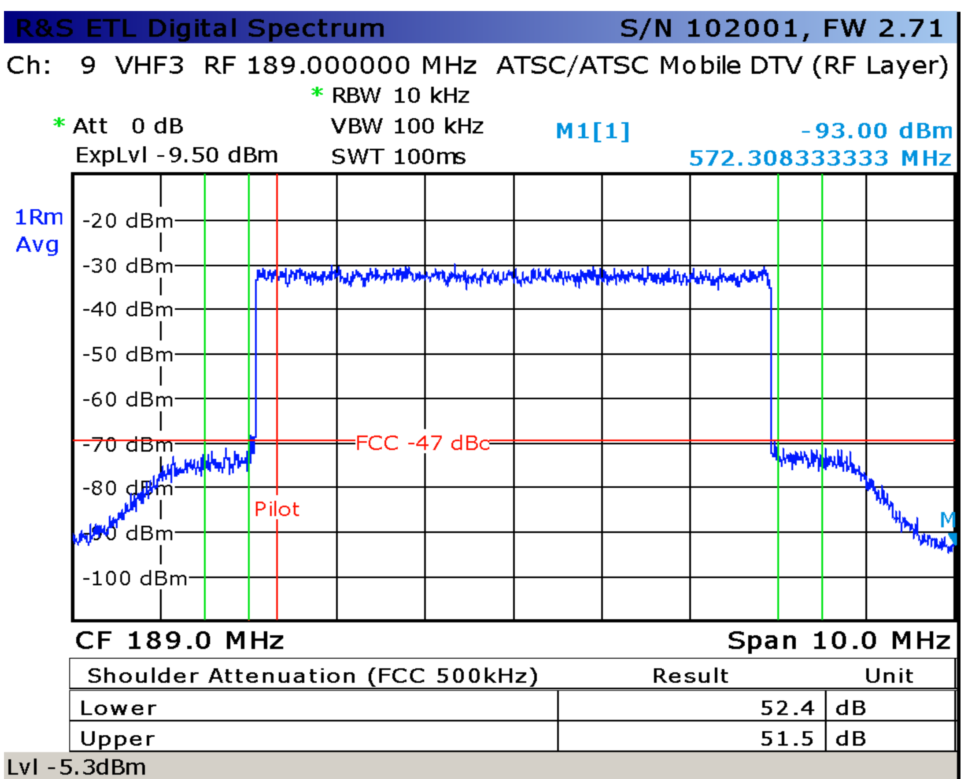


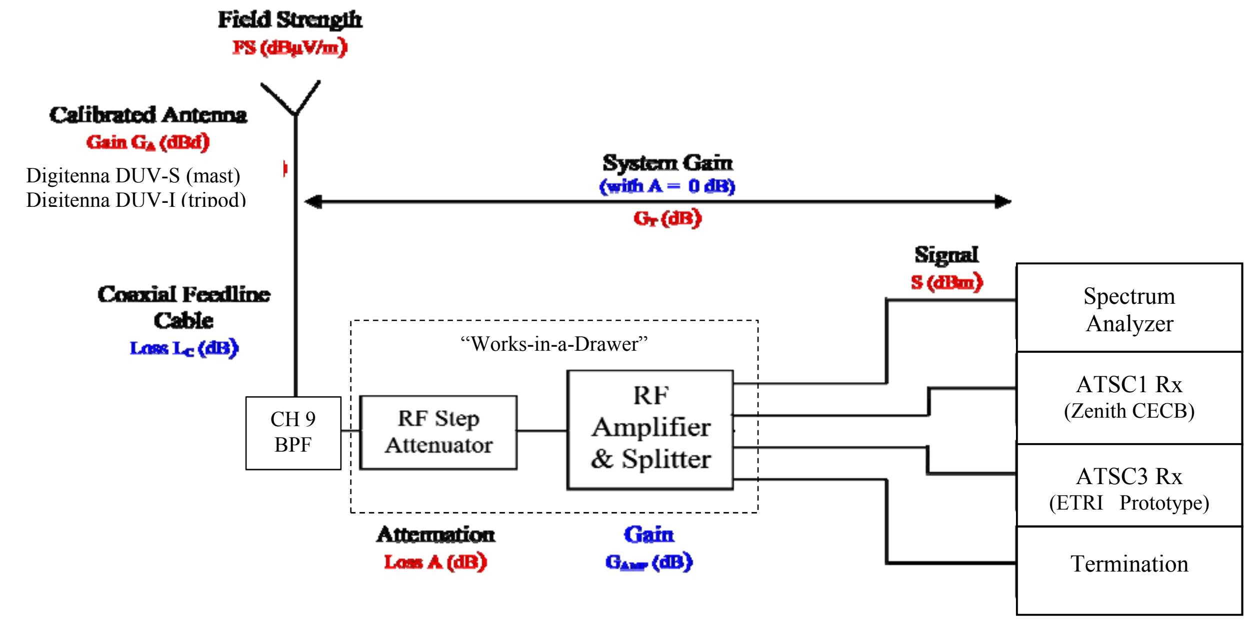
Figure A1-6b NAB CH9 ATSC3 transmitter spectrum.

APPENDIX 2 DTV Field Test Vehicle Description

The MSW field test van (shown below) was used for this field test. The van was fully-equipped with RF test equipment, along with a pneumatic mast with 30' AGL mast extension as well as a 5.5 kW AC power generator. A picture of the test van and a system block diagram are shown below.

Table A2-1 Summary of field test truck hardware and equipment used in the NAB Cleveland field test.

Item	Manufacturer	Model #	Comment
Outdoor Antenna	Digitenna	DUV-S	Consumer broadband directional
Indoor Antenna	Digitenna	DUV-I	Consumer broadband dipole
Coaxial Cable	Belden	RG-214	50-Ω, double-shielded, low-loss
Variable Attenuator	JFW	50DR-001-BNC	50-Ω, 1-dB, 10 dB step
Amplifier	Mini-Circuits	ZFL-1000VH	50-Ω, IP3>+38 dBm, NF≈4 dB
4-way Splitter	Mini-Circuits	ZFSC-4-1	50-Ω, BMC, ≈7 dB loss
DTV RX #1	Zenith	CECB	Coupon eligible converter box, with remote control
DTV RX #2	ETRI	Prototype	Prototype receiver
Spectrum Analyzer	Rohde & Schwarz	FSH-8	50-Ω, 8 GHz, handheld, with internal tracking generator
GPS Receiver	Garmin	GPS-76	Handheld GPS receiver w/ battery & ext. power supply



$$FS\ (dB\mu V/m) = S(dBm) - G_T(dB) + A(dB) + K_D\ (dB\mu V/m - dBm) - G_A(dB)$$

where:

- S ≡ signal level in 6 MHz bandwidth at spectrum analyzer input (dBm)
- G_T ≡ total system gain of truck with attenuator A = 0 dB (dB)
- A ≡ manual attenuator loss (dB)
- K_D ≡ *dipole factor for given RF test channel center frequency (dBµV/m)*
- G_A ≡ antenna forward gain over λ/2 matched-impedance dipole for given RF test channel (dBd)

Figure A2-1a DTV field test system block diagram used for *outdoor* (30' AGL & 15' AGL) testing.

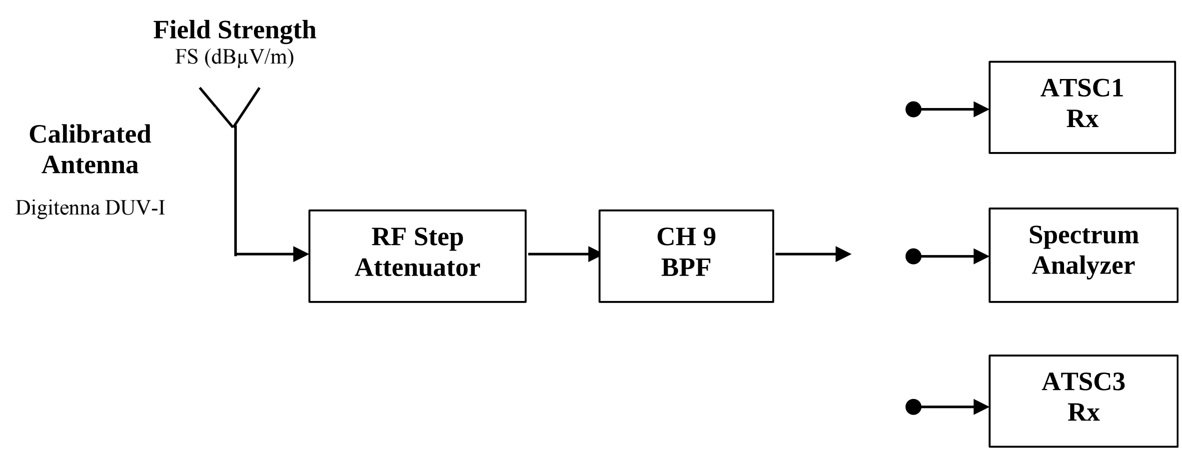


Figure A2-1b DTV field test system block diagram used for *indoor* (H-POL and V-POL) testing.

Figure A2-2a MSW field test truck exterior photo.

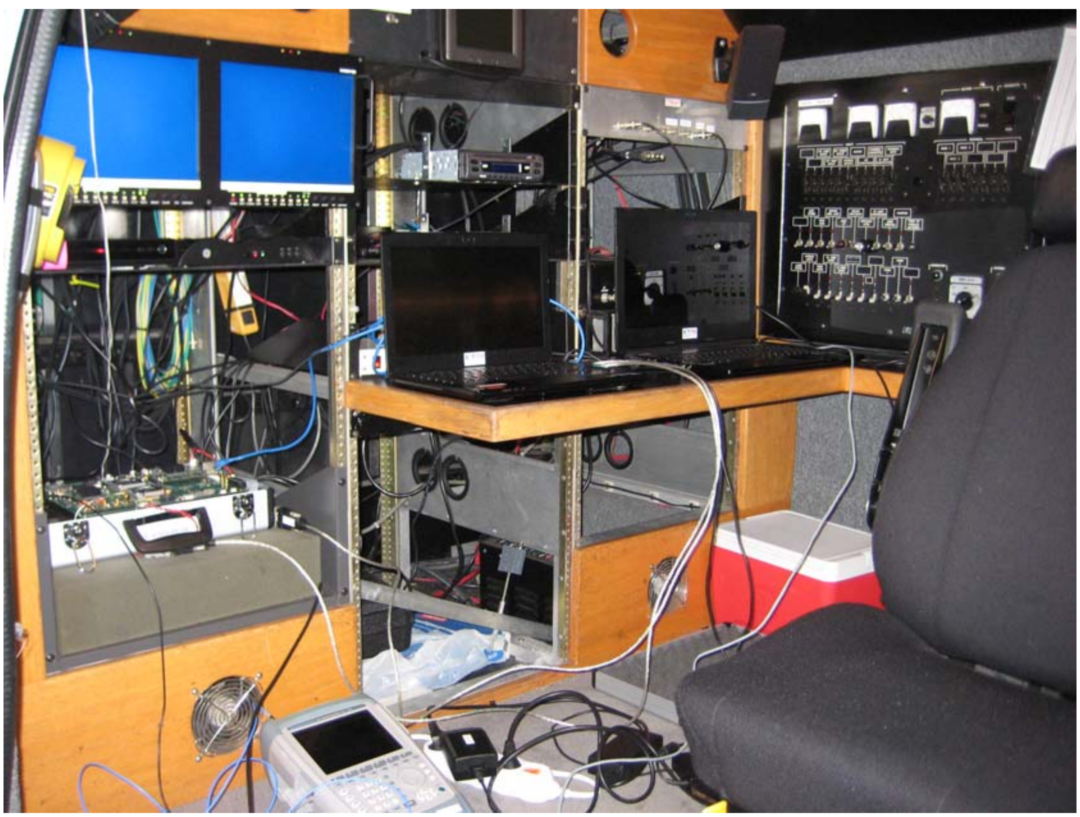


Figure A2-2b MSW field test truck interior photo.

21" L x 33" W x 11.8" H
Net Weight: 1.8 lbs
G ≈ 2.1 dBd

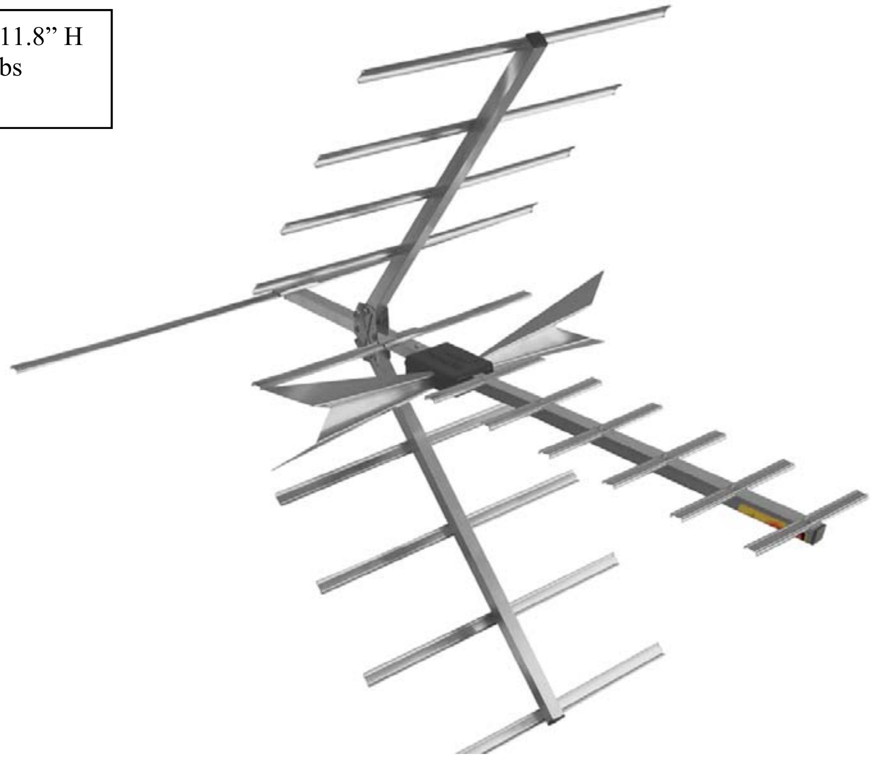


Figure A2-3a Digitenna **DUV-S** VHF/UHF directional receive antenna used in outdoor field test.

7" L x 21" W x 5.5" H
Net Weight: 0.8 lbs
G ≈ -0.7 dBd

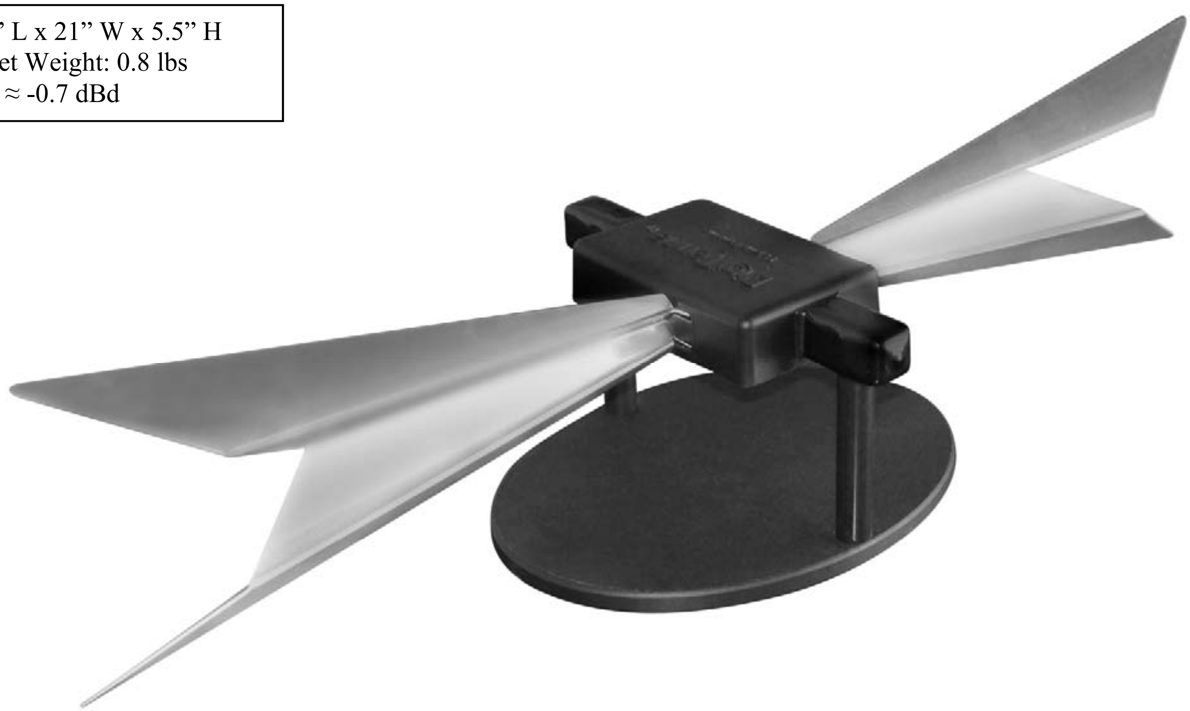


Figure A2-3b Digitenna **DUV-I** VHF/UHF bi-directional receive antenna used in indoor field test.

Figure A2-4a ETRI CH 9 band-pass filter.

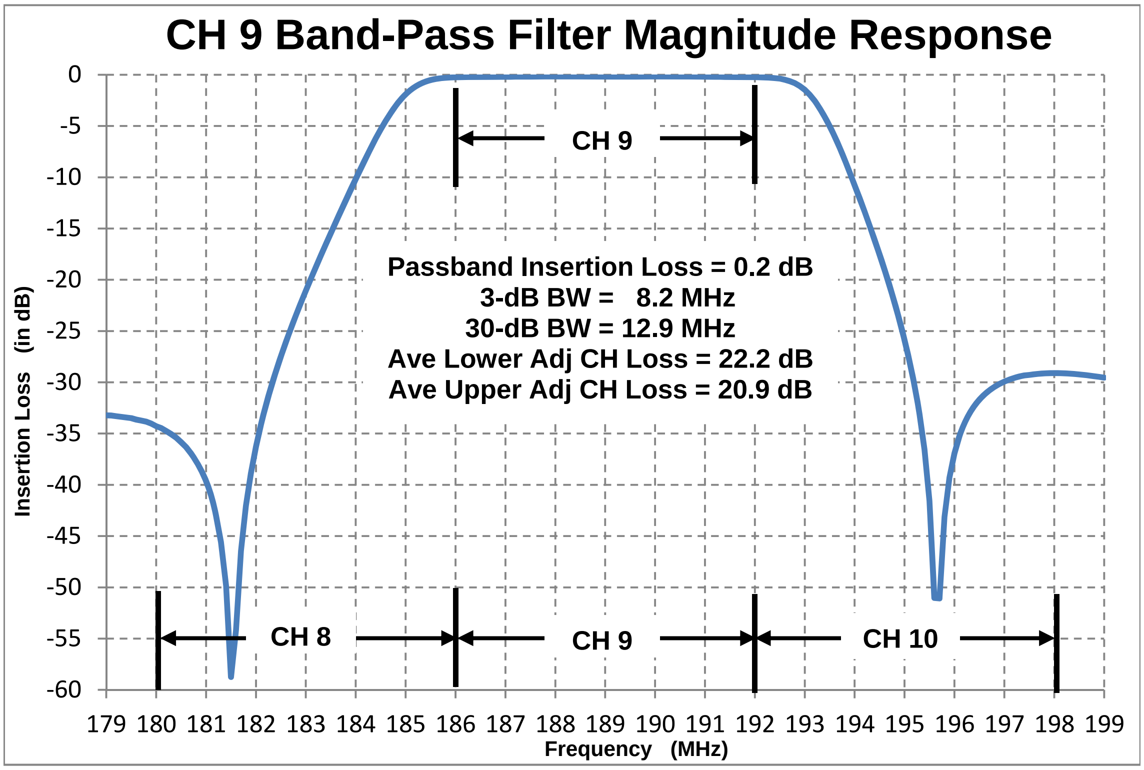


Figure A2-4b ETRI CH 9 band-pass filter magnitude response.

Figure A2-5a Zenith ATSC1 CECB receiver.

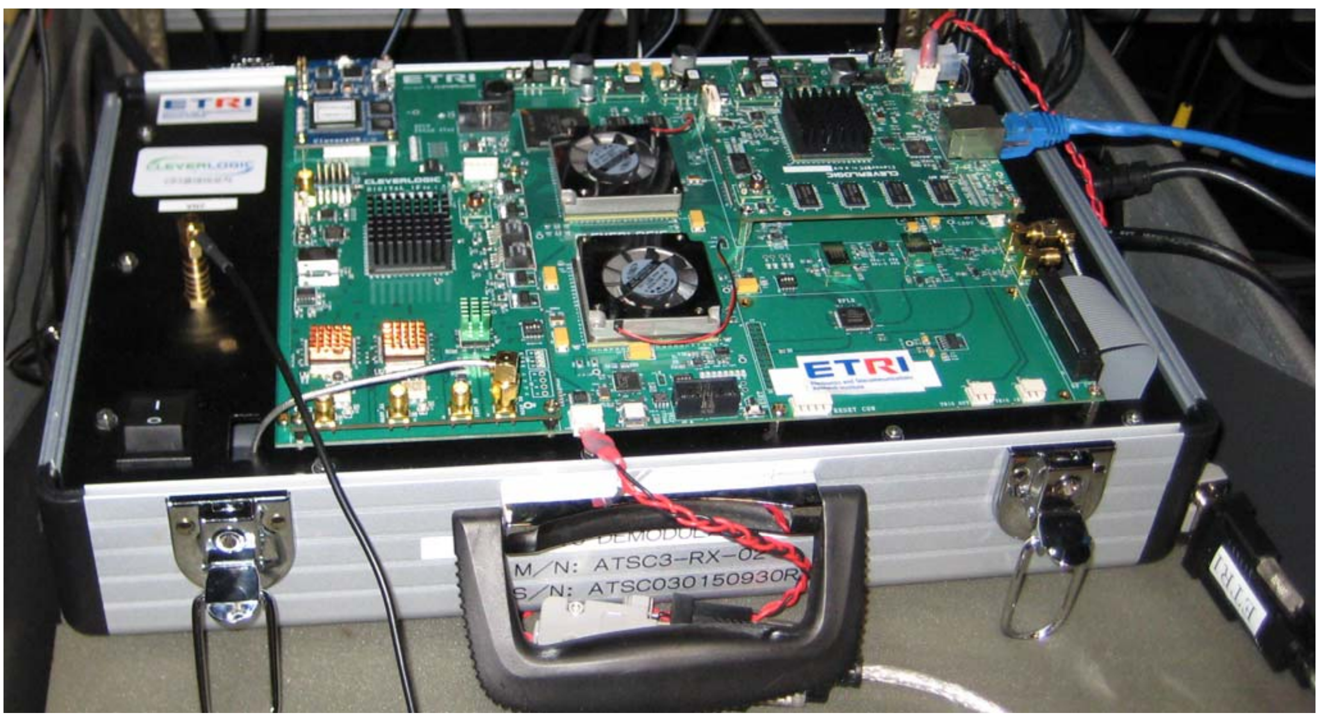


Figure A2-5b ETRI ATSC3 prototype receiver.

APPENDIX 3 Field Test Plan Details

Table A3-1 Detailed ATSC3 field test signal description.

General Parameters	Mode Parameter	ATSC3-A	ATSC3-B	ATSC3-C
Spectrum	Occupied BW	5.832844 MHz	5.832844 MHz	5.832844 MHz
	Inband SNR	38.3	38.3	38.3
	Stopband Shelves	42 dB	42 dB	42 dB
Preamble	FFT Size	32k	32k	16k
	SP_Dx	12	8	6
	Guard Interval	148.148	527.78	148.148
	L1-Basic Detail Mode	4	3	1
	# of Symbols	1	1	1
Payload OFDM	FFT Size	32k	32k	16k
	SP_Dx	12	8	6
	SP_Dy	2	2	2
	Guard Interval	148.148	527.78	148.148
	Pilot Boosting	Max	5.3 dB	Max
	# of Symbols	50	46	98
	Time Interleaver	CTI (1024)	CTI (1024)	CTI (1024)
	Frequency Interleaver	ON	ON	ON
Payload BICM	Inner FEC Code	11/15 LDPC[2]	10/15 LDPC[2]	5/15 LDPC[2]
	Outer FEC Code	BCH	BCH	BCH
	Constellation	64-QAM (NUC)[1]	64-QAM (NUC)[1]	QPSK
Frame with Bootstrap	Length	251.34 msec	249.63msec	251.34msec
Payload Performance	Data Rate	23.1667 MB/sec	19.0369 MB/sec	3.2333MB/sec
	BICM TOV[3]	14.28 dB	12.88 dB	-1.7 dB
	OFDM TOV[4]	14.98 dB	13.64 dB	-0.9 dB
	AWGN Lab Threshold[5]	16.04 dB	14.62 dB	+0.1 dB
	Sensitivity[6]	-85.3 dBm	-86.2 dBm	-100.25 dBm

[1] NUC means **Non-Uniform Constellation**

[2] LDPC means **Low Density Parity Code** (64800)

[3] BICM TOV means bit interleaved coded modulation threshold of visible errors

[4] OFDM TOV means orthogonal frequency division multiplexing threshold of visible errors

[5] As measured on CH 9 at -50 dBm in 0.1 dB steps using FEC detector after BCH decoder with FER threshold = 10^{-4}

[6] Minimum pristine (no impairments) receiver input signal level for threshold at CH 9

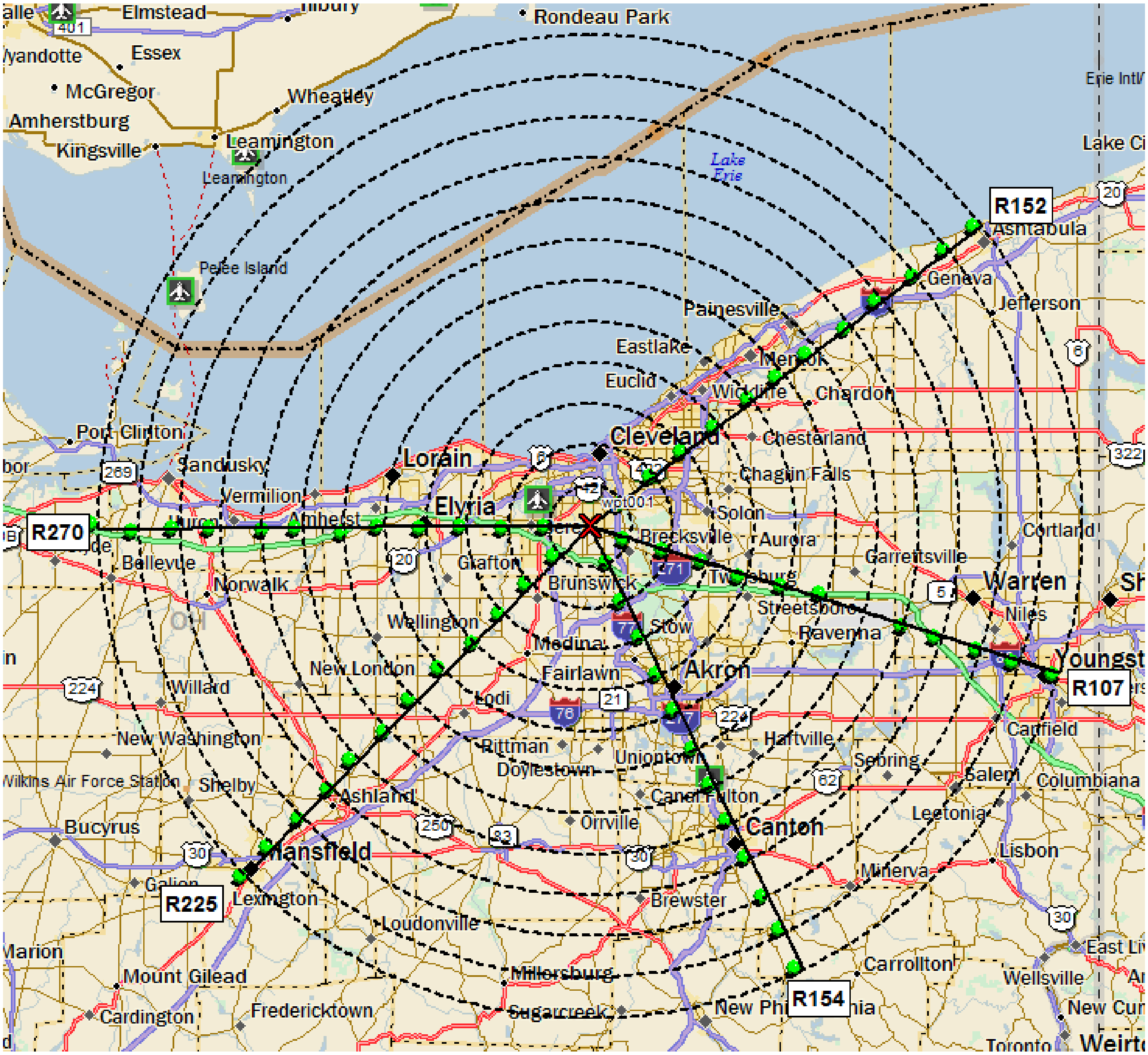


Figure A3-1a Map of Cleveland outdoor ***radial*** field test sites (60-mile radius). Dotted circles are in 5-mile increments.

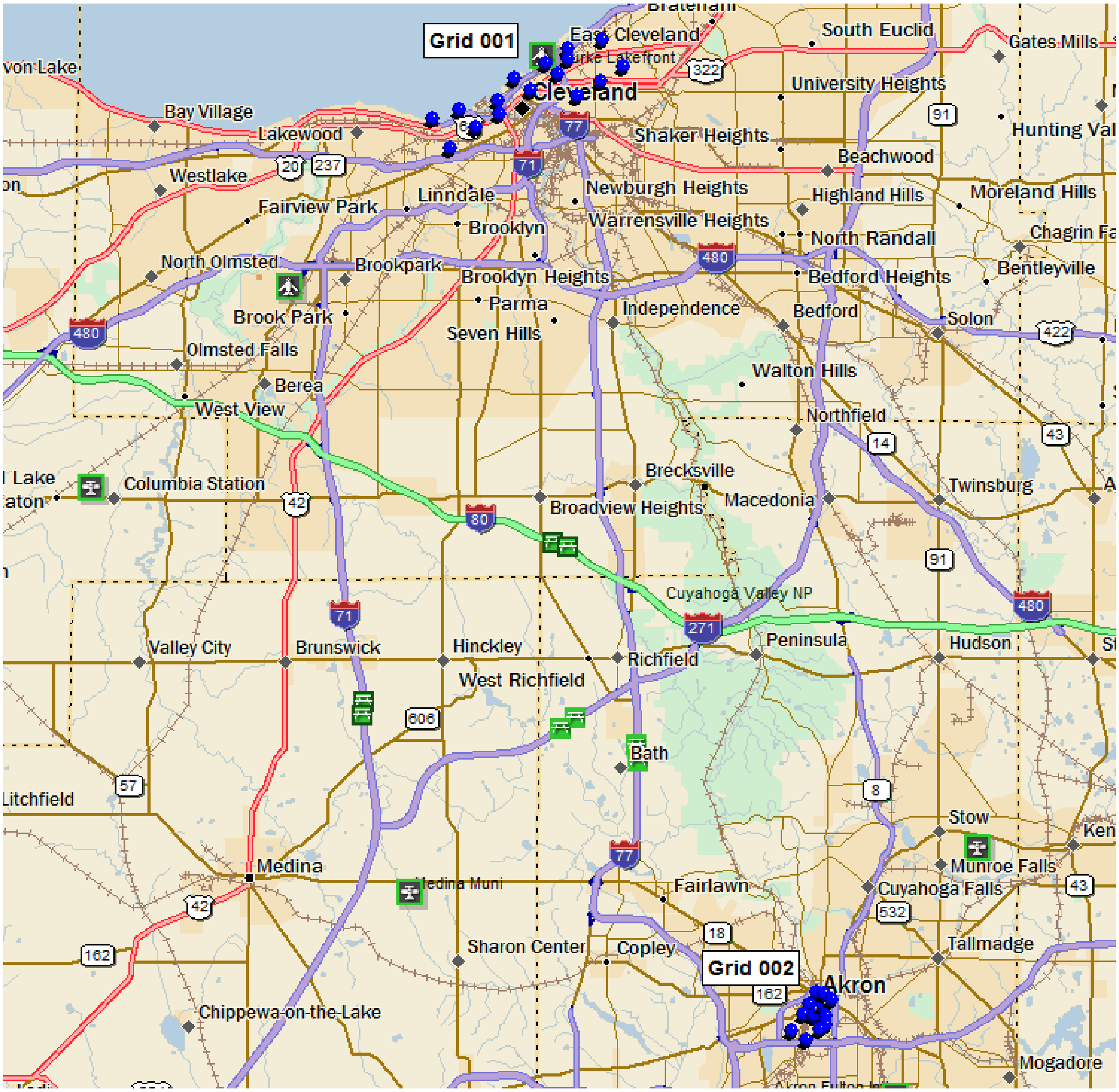


Figure A3-1b Map of Cleveland outdoor ***grid*** field test sites.

Figure A3-1c Map of Cleveland ***indoor*** field test sites.

Figure A3-1d Map of Cleveland ***outdoor*** failed ATSC3 field test sites where ATSC1 had reception. Purple triangles indicate *adjacent channel interference* and blue dots indicated *co-channel interference*.

APPENDIX 4 FIELD TEST DATA

Table A4-1a *Outdoor* **30'** AGL raw data summary.

Site Description			ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
Site #	Distance	Bearing	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR
R052-001	4.3	231	86.2	49.0	N.A.	79.9	37.0	16.4	83.0	43.0	14.7	83.6	61.0	-0.3
R052-002	9.4	229	80.9	43.0	N.A.	80.9	41.0	15.9	80.8	43.0	14.2	80.9	59.0	-1.2
R052-003	14.2	230	78.6	41.0	N.A.	78.6	41.0	15.2	78.6	42.0	14.2	78.6	57.0	-1.2
R052-004	19.3	231	53.5	16.0	N.A.	53.5	15.0	16.3	53.6	17.0	14.2	53.4	32.0	-1.2
R052-005	24.6	231	65.9	28.0	N.A.	66.0	27.0	15.9	65.9	29.0	14.2	65.9	44.0	-1.2
R052-006	29.1	231	75.8	38.0	N.A.	75.6	37.0	15.7	75.9	39.0	14.1	75.8	54.0	-1.2
R052-007	33.5	231	44.2	0.0	N.A.	45.4	0.0	---	45.5	0.0	---	45.5	13.0	-2.0
R052-008	39.2	232	48.9	10.0	N.A.	49.0	11.0	15.6	49.0	12.0	14.2	49.2	27.0	-1.2
R052-009	44.3	232	38.0	0.0	N.A.	38.4	0.0	---	38.5	0.0	---	38.6	16.0	-0.9
R052-010	49.7	232	32.7	0.0	N.A.	32.5	0.0	---	32.5	0.0	---	32.5	8.0	-0.3
R052-011	54.6	232	32.5	0.0	N.A.	30.7	0.0	---	30.7	0.0	---	30.7	9.0	-0.6
R052-012	59.3	232	31.9	0.0	N.A.	32.2	0.0	---	32.2	0.0	---	32.2	5.0	0.7
R107-001	4.2	291	64.3	26.0	N.A.	64.2	0.0	---	64.5	21.0	16.6	64.3	42.0	-0.9
R107-002	9.1	289	74.0	36.0	N.A.	73.5	30.0	16.5	73.4	33.0	14.9	73.6	51.0	-0.6
R107-003	14.0	287	65.3	27.0	N.A.	65.2	25.0	16.1	65.3	27.0	14.8	65.3	42.0	-0.3
R107-004	19.0	289	66.2	28.0	N.A.	66.3	25.0	16.4	66.2	27.0	14.8	66.2	44.0	-0.9
R107-005	24.3	287	59.0	22.0	N.A.	59.0	0.0	---	59.4	11.0	14.7	59.3	37.0	-0.6
R107-006	29.2	286	58.5	21.0	N.A.	58.5	20.0	15.6	58.4	21.0	14.6	58.5	36.0	-0.6
R107-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
R107-008	39.9	288	33.8	0.0	N.A.	34.2	0.0	---	34.2	0.0	---	34.2	11.0	-0.6
R107-009	44.2	288	34.1	0.0	N.A.	34.1	0.0	---	34.1	0.0	---	34.1	10.0	-0.6
R107-010	49.5	288	28.3	0.0	N.A.	28.3	0.0	---	28.3	0.0	---	28.3	0.0	---
R107-011	54.1	288	35.7	0.0	N.A.	35.6	0.0	---	35.7	0.0	---	35.5	12.0	-0.3
R107-012	59.3	288	27.4	0.0	N.A.	27.4	0.0	---	27.4	0.0	---	27.4	0.0	---
R154-001	4.7	337	94.8	57.0	N.A.	95.0	56.0	16.4	95.0	58.0	14.4	95.0	72.0	-0.3
R154-002	9.8	338	76.1	39.0	N.A.	76.2	38.0	15.9	76.2	39.0	14.5	76.2	54.0	-0.9
R154-003	14.7	336	56.0	18.0	N.A.	56.1	16.0	16.4	56.1	18.0	14.8	56.1	34.0	-0.6
R154-004	19.6	336	51.3	13.0	N.A.	51.5	0.0	---	51.7	0.0	---	51.7	29.0	-0.6
R154-005	24.6	336	64.9	27.0	N.A.	65.0	27.0	15.6	64.9	28.0	14.6	65.0	43.0	-0.9
R154-006	29.7	336	73.0	35.0	N.A.	73.0	35.0	15.7	73.1	36.0	14.4	73.1	51.0	-0.9
R154-007	34.7	335	58.9	0.0	N.A.	59.0	0.0	---	59.0	0.0	---	58.9	36.0	-0.9
R154-008	39.5	335	52.4	14.0	N.A.	52.7	13.0	16.3	52.5	15.0	14.6	52.6	30.0	-0.6
R154-009	44.6	335	44.3	0.0	N.A.	44.6	0.0	---	44.6	0.0	---	44.6	0.0	---
R154-010	49.7	335	46.3	0.0	N.A.	46.3	0.0	---	46.3	0.0	---	46.4	21.0	-0.9
R154-011	54.3	335	42.4	0.0	N.A.	43.0	0.0	---	43.1	0.0	---	43.1	14.0	-1.2
R154-012	59.4	335	42.3	0.0	N.A.	42.5	0.0	---	42.5	0.0	---	42.5	0.0	---
R225-001	5.8	51	89.9	52.0	N.A.	89.9	51.0	16.4	90.0	53.0	14.5	89.9	67.0	-0.3
R225-002	10.6	49	78.6	41.0	N.A.	78.6	40.0	16.2	78.7	41.0	14.8	78.7	56.0	-0.3
R225-003	15.5	47	80.9	43.0	N.A.	81.0	43.0	15.8	81.0	44.0	14.4	81.0	59.0	-0.6
R225-004	20.3	45	80.5	43.0	N.A.	80.6	42.0	16.0	80.7	44.0	14.1	80.7	59.0	-0.9
R225-005	25.5	47	59.5	22.0	N.A.	59.7	21.0	16.2	59.5	22.0	14.8	59.6	38.0	-0.3
R225-006	30.7	46	79.2	42.0	N.A.	79.3	41.0	15.6	79.3	42.0	14.4	79.2	57.0	-0.9

Note: No data was taken at R107-07 since it was located in the middle of a National Guard army base, and therefore inaccessible.

Table A4-1a (cont) *Outdoor* **30'** AGL field test raw data summary.

Site Description			ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
Site #	Distance	Bearing	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR
R225-007	35.6	45	69.4	32.0	N.A.	69.7	31.0	16.3	69.5	33.0	14.1	70.3	47.0	-0.9
R225-008	41.0	46	61.9	24.0	N.A.	62.0	23.0	16.4	61.9	25.0	14.6	62.0	40.0	-0.9
R225-009	45.5	45	55.4	18.0	N.A.	55.5	17.0	16.1	55.6	18.0	14.9	55.6	33.0	-0.6
R225-010	50.6	45	51.4	14.0	N.A.	51.5	13.0	16.1	51.3	15.0	14.1	51.5	29.0	-0.6
R225-011	55.7	45	55.9	18.0	N.A.	56.0	18.0	15.6	56.0	19.0	14.7	55.8	34.0	-1.2
R225-012	60.6	45	49.3	12.0	N.A.	49.5	11.0	15.7	49.3	12.0	14.7	49.4	27.0	-0.6
R270-001	5.7	91	95.5	58.0	N.A.	95.5	57.0	15.9	95.5	59.0	13.9	95.5	73.0	-0.6
R270-002	10.9	89	85.8	48.0	N.A.	85.9	48.0	15.4	86.0	49.0	14.1	85.9	63.0	-0.3
R270-003	16.1	90	70.4	32.0	N.A.	70.4	32.0	15.8	70.3	33.0	14.7	70.4	48.0	-0.6
R270-004	21.0	89	70.8	33.0	N.A.	70.6	32.0	16.1	70.8	34.0	14.5	70.9	49.0	-1.2
R270-005	26.1	90	71.8	34.0	N.A.	71.7	33.0	16.3	71.6	35.0	14.0	71.5	49.0	-0.3
R270-006	30.5	89	60.0	22.0	N.A.	60.0	21.0	16.7	59.9	22.0	15.3	60.1	37.0	0.0
R270-007	36.2	89	58.0	20.0	N.A.	58.0	20.0	15.8	58.0	21.0	14.4	57.7	36.0	-0.9
R270-008	40.1	89	51.9	14.0	N.A.	52.1	13.0	16.6	52.2	15.0	14.6	52.1	30.0	-0.6
R270-009	46.7	89	56.3	19.0	N.A.	56.4	18.0	15.9	56.3	20.0	13.9	56.2	34.0	-0.9
R270-010	51.1	89	53.4	16.0	N.A.	53.6	15.0	15.0	53.5	17.0	14.0	53.6	31.0	-0.3
R270-011	56.1	89	48.5	11.0	N.A.	48.7	10.0	16.0	48.6	11.0	14.7	48.5	26.0	-0.6
R270-012	61.1	90	41.4	2.0	N.A.	41.6	1.0	15.8	41.6	2.0	14.8	41.4	19.0	-0.9
G001-001	8.9	168	69.4	26.0	N.A.	70.0	0.0	---	70.0	0.0	---	70.6	43.0	2.7
G001-002	9.0	174	84.4	47.0	N.A.	84.3	46.0	15.7	84.4	47.0	14.4	84.3	62.0	-0.9
G001-003	9.2	182	68.0	28.0	N.A.	68.7	0.0	---	68.7	0.0	---	68.2	45.0	0.0
G001-004	10.0	184	62.4	24.0	N.A.	63.5	0.0	---	63.5	0.0	---	61.5	38.0	0.5
G001-005	10.6	190	60.5	20.0	N.A.	60.6	0.0	---	60.6	0.0	---	60.6	37.0	0.0
G001-006	11.2	193	70.7	33.0	N.A.	70.8	32.0	16.5	70.5	34.0	14.2	70.5	48.0	-0.6
G001-007	12.2	197	65.8	28.0	N.A.	65.9	27.0	16.2	67.5	30.0	14.9	69.4	47.0	-0.9
G001-008	11.7	198	75.9	38.0	N.A.	76.1	38.0	15.7	76.1	39.0	14.4	76.1	53.0	-0.3
G001-009	10.9	193	77.6	40.0	N.A.	77.6	39.0	16.2	77.5	40.0	14.8	77.5	55.0	-0.6
G001-010	10.3	192	66.5	28.0	N.A.	66.6	27.0	16.5	65.1	26.0	16.2	64.2	41.0	0.0
G001-011	9.7	188	62.0	18.0	N.A.	61.8	0.0	---	62.3	0.0	---	63.3	41.0	-0.6
G001-012	8.8	182	78.4	41.0	N.A.	78.4	40.0	15.7	79.1	41.0	14.6	78.8	56.0	-0.3
G001-013	8.4	177	77.9	40.0	N.A	77.9	40.0	15.6	78.0	41.0	14.3	78.0	56.0	-0.9
G001-014	7.8	171	80.9	43.0	N.A	81.0	42.0	16.2	80.9	44.0	14.1	81.0	59.0	-1.2
G001-015	9.8	196	83.9	46.0	N.A	84.0	46.0	15.5	84.0	47.0	14.1	84.0	62.0	-0.9
G001-016	10.5	200	78.5	41.0	N.A	78.5	40.0	16.0	78.5	41.0	14.6	78.3	56.0	-0.6
G001-017	11.2	202	74.1	36.0	N.A	74.0	36.0	15.7	74.2	37.0	14.5	73.7	52.0	-0.9
G002-001	21.9	332	63.7	26.0	N.A.	63.7	25.0	16.3	63.8	27.0	14.2	63.8	41.0	-0.3
G002-002	22.1	333	52.5	10.0	N.A.	52.8	0.0	---	51.1	9.0	17.3	53.0	29.0	1.0
G002-003	22.3	333	60.4	22.0	N.A.	60.3	0.0	---	60.3	0.0	---	60.6	38.0	-0.3
G002-004	22.6	335	62.7	25.0	N.A.	62.9	24.0	16.1	62.8	26.0	14.1	62.8	40.0	-0.6
G002-005	23.0	334	67.1	29.0	N.A.	67.1	29.0	15.8	67.1	30.0	14.4	67.1	45.0	-0.6
G002-006	22.5	333	63.3	25.0	N.A.	63.0	24.0	16.3	62.9	26.0	14.7	63.1	41.0	-0.9
G002-007	22.3	332	62.0	23.0	N.A.	61.9	23.0	16.6	62.0	24.0	15.0	62.0	40.0	-0.9
G002-008	22.0	331	83.9	46.0	N.A.	84.0	46.0	15.4	84.0	47.0	14.2	84.1	62.0	-0.9
G002-009	22.3	331	76.2	39.0	N.A.	76.2	38.0	15.7	76.2	39.0	14.6	76.2	54.0	-0.6
G002-010	22.6	332	64.6	27.0	N.A.	64.5	26.0	15.5	64.4	27.0	14.2	64.5	42.0	-0.6
G002-011	22.9	332	55.6	16.0	N.A.	55.7	0.0	---	55.9	13.0	16.9	55.7	33.0	-0.3
G002-012	22.9	333	59.7	22.0	N.A.	59.7	21.0	16.3	59.7	23.0	14.1	59.8	37.0	-0.9

Table A4-1b *Outdoor* **15'** AGL field test raw data summary.

Site Description			ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
Site #	Distance	Bearing	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR
R052-001	4.3	231	77.3	39.0	N.A.	77.4	0.0	---	77.3	0.0	---	77.4	55.0	-0.3
R052-002	9.4	229	76.1	39.0	N.A.	75.9	0.0	16.2	75.8	32.0	14.2	75.7	53.0	-0.3
R052-003	14.2	230	70.2	32.0	N.A.	70.3	32.0	15.1	70.3	33.0	14.4	70.3	48.0	-0.9
R052-004	19.3	231	53.7	16.0	N.A.	54.2	16.0	15.6	54.0	17.0	14.4	54.0	32.0	-0.9
R052-005	24.6	231	55.6	16.0	N.A.	55.4	15.0	16.5	55.5	17.0	15.7	55.4	33.0	-0.3
R052-006	29.1	231	72.7	35.0	N.A.	72.8	34.0	15.3	72.8	36.0	13.9	72.7	51.0	-1.2
R052-007	33.5	231	45.8	0.0	N.A.	45.8	0.0	---	45.8	0.0	---	45.8	0.0	---
R052-008	39.2	232	49.6	13.0	N.A.	50.5	12.0	15.7	50.5	14.0	14.6	50.4	28.0	-0.6
R052-009	44.3	232	34.2	0.0	N.A.	34.4	0.0	---	34.6	0.0	---	34.2	10.0	-0.6
R052-010	49.7	232	27.7	0.0	N.A.	29.1	0.0	---	29.1	0.0	---	29.1	2.0	-1.6
R052-011	54.6	232	33.2	0.0	N.A.	33.2	0.0	---	33.2	0.0	---	33.2	9.0	-0.9
R052-012	59.3	232	29.4	0.0	N.A.	30.4	0.0	---	30.4	0.0	---	30.4	0.0	---
R107-001	4.2	291	67.5	29.0	N.A.	67.5	24.0	17.1	67.6	26.0	15.9	67.4	45.0	-0.3
R107-002	9.1	289	65.7	27.0	N.A.	65.3	0.0	---	65.4	0.0	---	65.6	42.0	0.0
R107-003	14.0	287	57.7	20.0	N.A.	57.9	0.0	---	57.7	16.0	14.8	57.9	35.0	-0.3
R107-004	19.0	289	62.2	24.0	N.A.	62.0	0.0	---	62.1	0.0	---	62.1	39.0	-0.3
R107-005	24.3	287	52.8	14.0	N.A.	53.0	0.0	---	53.0	0.0	---	53.0	30.0	-0.3
R107-006	29.2	286	50.7	12.0	N.A.	50.5	0.0	---	50.4	0.0	---	50.6	28.0	-0.6
R107-07	---	---	---	---	---	---	---	---	---	---	---	---	---	---
R107-008	39.9	288	27.7	0.0	N.A.	27.4	0.0	---	27.4	0.0	---	27.5	0.0	---
R107-009	44.2	288	34.9	0.0	N.A.	35.0	0.0	---	35.0	0.0	---	35.0	11.0	-0.6
R107-010	49.5	288	29.9	0.0	N.A.	29.9	0.0	---	29.9	0.0	---	29.9	0.0	---
R107-011	54.1	288	29.9	0.0	N.A.	30.2	0.0	---	30.3	0.0	---	30.2	0.0	---
R107-012	59.3	288	28.1	0.0	N.A.	28.3	0.0	---	28.3	0.0	---	28.3	0.0	---
R154-001	4.7	337	97.0	58.0	N.A.	97.1	58.0	16.7	97.0	60.0	14.7	97.0	75.0	-0.6
R154-002	9.8	338	75.0	37.0	N.A.	75.3	37.0	15.9	75.3	38.0	14.7	75.4	53.0	-0.9
R154-003	14.7	336	54.6	17.0	N.A.	54.8	15.0	16.5	54.9	17.0	14.9	54.9	33.0	-1.2
R154-004	19.6	336	58.1	20.0	N.A.	58.3	20.0	15.9	58.5	21.0	14.6	58.5	36.0	-0.6
R154-005	24.6	336	53.6	15.0	N.A.	53.7	14.0	16.6	53.8	16.0	14.5	53.7	31.0	-0.6
R154-006	29.7	336	68.4	30.0	N.A.	68.4	29.0	16.7	68.4	30.0	15.5	68.2	46.0	-0.6
R154-007	34.7	335	53.1	0.0	N.A.	53.4	0.0	---	53.3	0.0	---	53.4	31.0	-0.6
R154-008	39.5	335	39.1	0.0	N.A.	39.1	0.0	---	39.2	0.0	---	39.1	16.0	-1.2
R154-009	44.6	335	42.9	0.0	N.A.	42.4	0.0	---	42.4	0.0	---	42.4	0.0	---
R154-010	49.7	335	42.9	0.0	N.A.	42.9	0.0	---	42.9	0.0	---	42.9	0.0	---
R154-011	54.3	335	40.5	0.0	N.A.	41.6	0.0	---	41.6	0.0	---	41.6	4.0	-1.6
R154-012	59.4	335	43.3	0.0	N.A.	43.4	0.0	---	43.4	0.0	---	43.4	0.0	---
R225-001	5.8	51	88.6	51.0	N.A.	88.4	50.0	16.1	88.4	51.0	14.6	88.5	66.0	-0.9
R225-002	10.6	49	79.2	41.0	N.A.	79.3	41.0	15.7	79.2	42.0	14.6	79.3	57.0	-0.6
R225-003	15.5	47	77.4	40.0	N.A.	77.4	39.0	16.0	77.4	40.0	14.8	77.4	55.0	-0.3
R225-004	20.3	45	75.1	37.0	N.A.	75.3	37.0	15.7	75.2	38.0	14.7	75.1	53.0	-0.6
R225-005	25.5	47	58.5	20.0	N.A.	57.8	19.0	16.1	57.9	21.0	14.1	57.9	35.0	-0.3
R225-006	30.7	46	78.6	41.0	N.A.	78.6	40.0	16.0	78.6	42.0	13.9	78.6	56.0	-0.3

Note: No data was taken at R107-07 since it was located in the middle of a National Guard army base, and therefore inaccessible.

Table A4-1b (cont) *Outdoor* **15'** AGL field test raw data summary.

Site Description			ATSC1			ATSC3-A			ATSC3-B			ATSC3-C		
Site #	Distance	Bearing	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR	F.S.	Margin	THR SNR
R225-007	35.6	45	66.3	29.0	N.A.	66.4	28.0	15.9	66.3	30.0	14.1	66.4	44.0	-0.9
R225-008	41.0	46	56.8	19.0	N.A.	56.5	18.0	16.2	56.6	20.0	14.0	56.5	34.0	-0.6
R225-009	45.5	45	50.4	14.0	N.A.	50.4	12.0	15.7	50.4	13.0	14.7	50.4	28.0	-0.9
R225-010	50.6	45	44.5	6.0	N.A.	44.5	5.0	16.0	44.5	7.0	14.3	44.4	22.0	-0.6
R225-011	55.7	45	48.7	11.0	N.A.	48.8	10.0	15.7	49.0	11.0	14.7	48.8	27.0	-1.2
R225-012	60.6	45	44.1	6.0	N.A.	44.0	5.0	16.0	44.0	6.0	14.7	44.1	22.0	-0.6
R270-001	5.7	91	90.3	53.0	N.A.	90.3	52.0	15.7	90.3	53.0	14.4	90.3	68.0	-0.9
R270-002	10.9	89	83.4	46.0	N.A.	83.4	45.0	15.7	83.4	46.0	14.5	83.3	61.0	-0.9
R270-003	16.1	90	67.3	29.0	N.A.	67.3	28.0	16.6	67.2	30.0	14.6	67.4	45.0	-1.2
R270-004	21.0	89	59.3	21.0	N.A.	59.2	20.0	16.6	59.3	22.0	14.8	59.3	37.0	-0.6
R270-005	26.1	90	76.6	39.0	N.A.	76.6	38.0	16.3	76.6	39.0	15.0	76.6	54.0	-0.3
R270-006	30.5	89	62.0	24.0	N.A.	61.6	23.0	16.6	61.6	25.0	14.3	61.9	39.0	0.0
R270-007	36.2	89	55.0	17.0	N.A.	54.9	16.0	16.3	55.0	18.0	14.4	54.9	33.0	-1.2
R270-008	40.1	89	47.0	9.0	N.A.	47.1	8.0	16.1	46.9	10.0	14.2	47.1	24.0	-0.6
R270-009	46.7	89	52.1	12.0	N.A.	50.1	12.0	15.6	50.2	13.0	14.4	50.2	28.0	-0.9
R270-010	51.1	89	44.9	6.0	N.A.	45.0	5.0	16.1	45.0	7.0	14.5	44.9	23.0	-1.2
R270-011	56.1	89	42.4	2.0	N.A.	42.4	1.0	16.2	42.4	3.0	14.7	42.3	20.0	-0.6
R270-012	61.1	90	35.5	0.0	N.A.	35.5	0.0	---	35.7	0.0	---	35.7	13.0	-0.6
G001-001	8.9	168	71.0	33.0	N.A.	71.2	30.0	18.0	71.3	33.0	15.3	71.2	49.0	-0.9
G001-002	9.0	174	81.0	43.0	N.A.	80.9	43.0	15.5	80.9	44.0	14.2	81.0	58.0	-0.3
G001-003	9.2	182	63.0	0.0	N.A.	63.4	0.0	---	63.4	0.0	---	63.2	40.0	0.0
G001-004	10.0	184	53.9	0.0	N.A.	53.8	0.0	---	53.8	0.0	---	54.1	29.0	1.2
G001-005	10.6	190	66.5	28.0	N.A.	66.3	25.0	18.6	66.4	28.0	15.7	66.4	44.0	-0.9
G001-006	11.2	193	61.8	23.0	N.A.	64.3	0.0	---	64.7	27.0	14.8	64.4	42.0	-0.6
G001-007	12.2	197	55.7	17.0	N.A.	53.4	0.0	---	53.4	0.0	---	53.4	31.0	-0.3
G001-008	11.7	198	66.0	27.0	N.A.	66.2	27.0	16.4	66.5	29.0	14.4	66.2	43.0	-0.6
G001-009	10.9	193	64.0	25.0	N.A.	64.0	24.0	16.8	64.1	26.0	14.5	63.9	41.0	0.0
G001-010	10.3	192	62.5	22.0	N.A.	62.5	0.0	---	62.4	0.0	---	62.4	39.0	0.0
G001-011	9.7	188	65.0	26.0	N.A.	64.9	0.0	---	65.2	0.0	---	65.4	42.0	-0.3
G001-012	8.8	182	75.4	37.0	N.A.	75.5	36.0	16.9	75.4	39.0	14.0	75.6	53.0	-0.6
G001-013	8.4	177	79.8	42.0	N.A	79.9	42.0	15.5	79.8	43.0	14.1	79.6	57.0	-0.3
G001-014	7.8	171	72.0	34.0	N.A	72.4	33.0	16.8	72.2	35.0	14.8	72.4	50.0	-0.6
G001-015	9.8	196	76.3	38.0	N.A	76.5	36.0	17.8	76.5	38.0	15.8	76.5	54.0	-0.3
G001-016	10.5	200	77.2	39.0	N.A	77.0	38.0	16.3	77.1	40.0	14.0	77.1	55.0	-0.9
G001-017	11.2	202	66.2	28.0	N.A	65.8	27.0	16.4	66.3	28.0	14.6	65.7	43.0	-0.3
G002-001	21.9	332	50.8	0.0	N.A.	50.7	0.0	---	50.9	0.0	---	50.6	27.0	0.7
G002-002	22.1	333	62.6	24.0	N.A.	61.9	23.0	16.9	62.8	26.0	14.2	62.7	40.0	-0.3
G002-003	22.3	333	52.4	12.0	N.A.	52.5	0.0	---	52.5	0.0	---	52.4	29.0	0.3
G002-004	22.6	335	56.4	18.0	N.A.	56.6	18.0	16.1	56.4	19.0	14.9	56.6	34.0	-0.6
G002-005	23.0	334	61.7	24.0	N.A.	60.5	22.0	16.1	60.5	23.0	14.9	60.6	38.0	-0.6
G002-006	22.5	333	60.5	23.0	N.A.	61.3	23.0	15.9	61.2	24.0	14.2	61.2	39.0	-0.3
G002-007	22.3	332	55.4	14.0	N.A.	55.5	14.0	18.8	55.6	16.0	16.6	55.8	33.0	-0.3
G002-008	22.0	331	76.2	39.0	N.A.	76.2	38.0	15.7	76.3	39.0	14.8	76.3	54.0	-0.6
G002-009	22.3	331	68.8	31.0	N.A.	68.9	30.0	16.4	68.9	32.0	14.3	68.9	47.0	-1.2
G002-010	22.6	332	65.5	27.0	N.A.	62.5	22.0	16.1	62.5	24.0	14.7	62.6	40.0	-0.6
G002-011	22.9	332	53.4	14.0	N.A.	54.0	10.0	18.9	54.2	14.0	16.6	54.1	31.0	0.0
G002-012	22.9	333	49.1	0.0	N.A.	49.2	0.0	---	48.9	6.0	18.8	48.8	25.0	1.0

Table A4-2 *Outdoor* field test data analysis summary.

Test Signal	Performance Parameter	30’ AGL Receive Antenna	15’ AGL Receive Antenna	Parameter Units
ATSC1	Service	83.0	76.1	%
	System Performance Index	91.3	85.9	%
	Upgraded Tuner Estimated Service	-----	-----	%
	Median Field Strength	63.0	58.3	dBμV/m
	Median Margin	28.0	25.0	dB
	Median Threshold SNR	-----	-----	dB
ATSC3-A	Service	70.5	62.5	%
	System Performance Index	78.5	70.5	%
	Upgraded Tuner Estimated Service	76.1	70.5	%
	Median Field Strength	63.3	58.1	dBμV/m
	Median Margin	29.5	24.0	dB
	Median Threshold SNR	16.0	16.1	dB
ATSC3-B	Service	75.0	67.0	%
	System Performance Index	82.5	75.6	%
	Upgraded Tuner Estimated Service	79.5	75.0	%
	Median Field Strength	63.2	58.2	dBμV/m
	Median Margin	29.5	26.0	dB
	Median Threshold SNR	14.5	14.6	dB
ATSC3-C	Service	95.5	89.8	%
	System Performance Index	95.5	89.8	%
	Upgraded Tuner Estimated Service	95.5	89.8	%
	Median Field Strength	63.2	58.2	dBμV/m
	Median Margin	41.0	39.0	dB
	Median Threshold SNR	-0.6	-0.6	dB

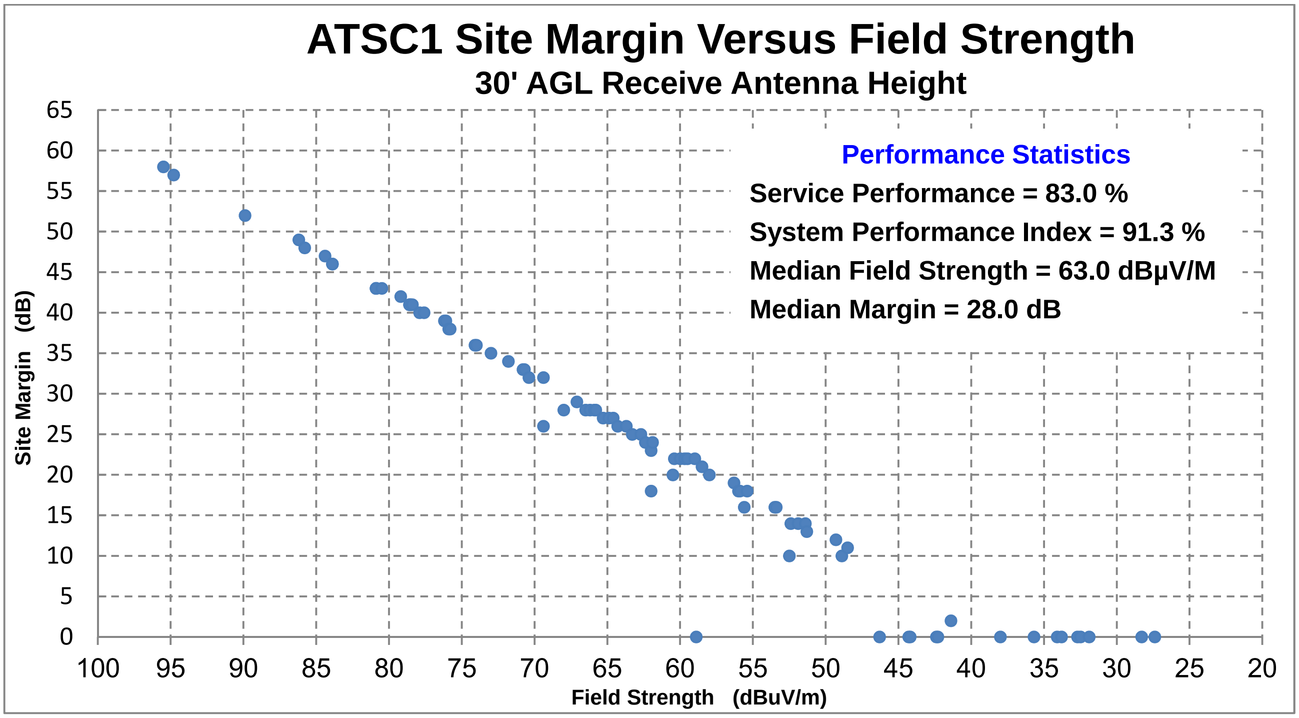


Figure A4-1a ATSC1 field strength versus service margin plot at 30' AGL

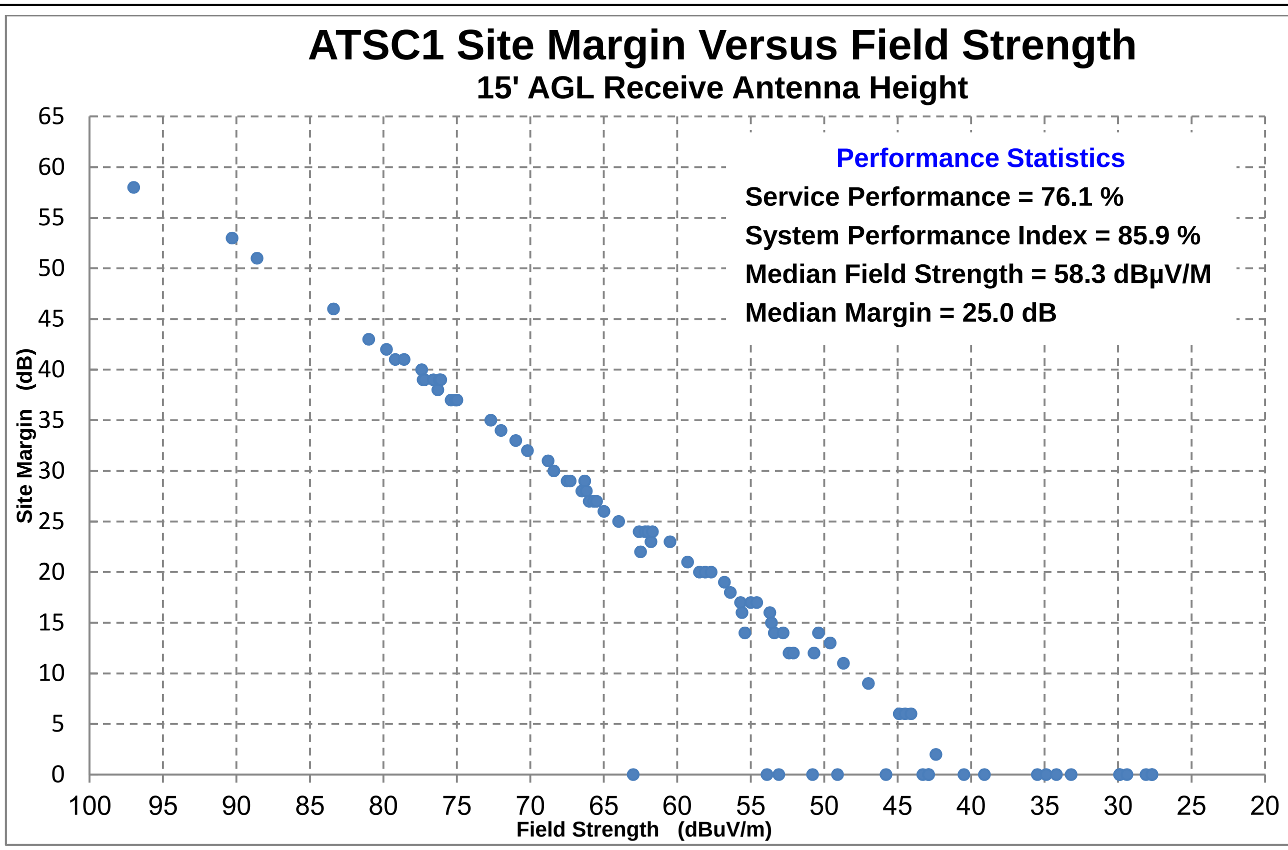


Figure A4-1b ATSC1 field strength versus service margin plot at 15' AGL.

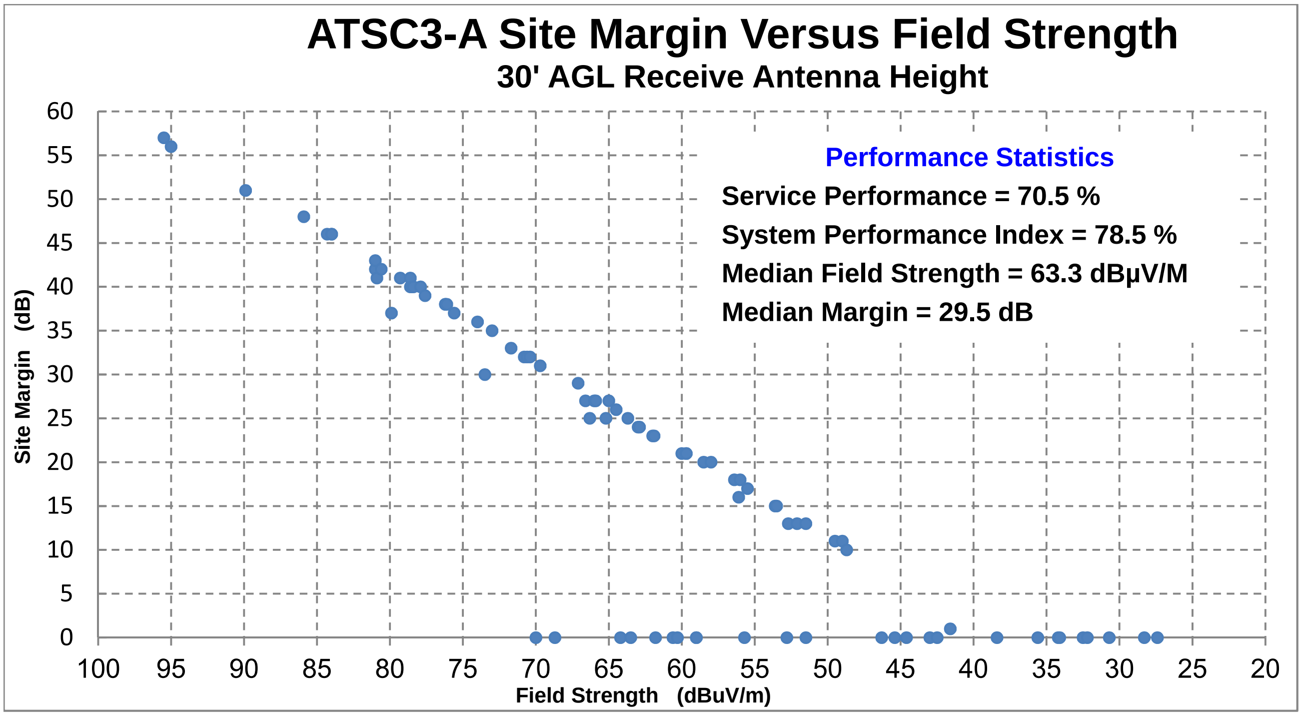


Figure A4-1c ATSC3-A field strength versus service margin plot at 30' AGL

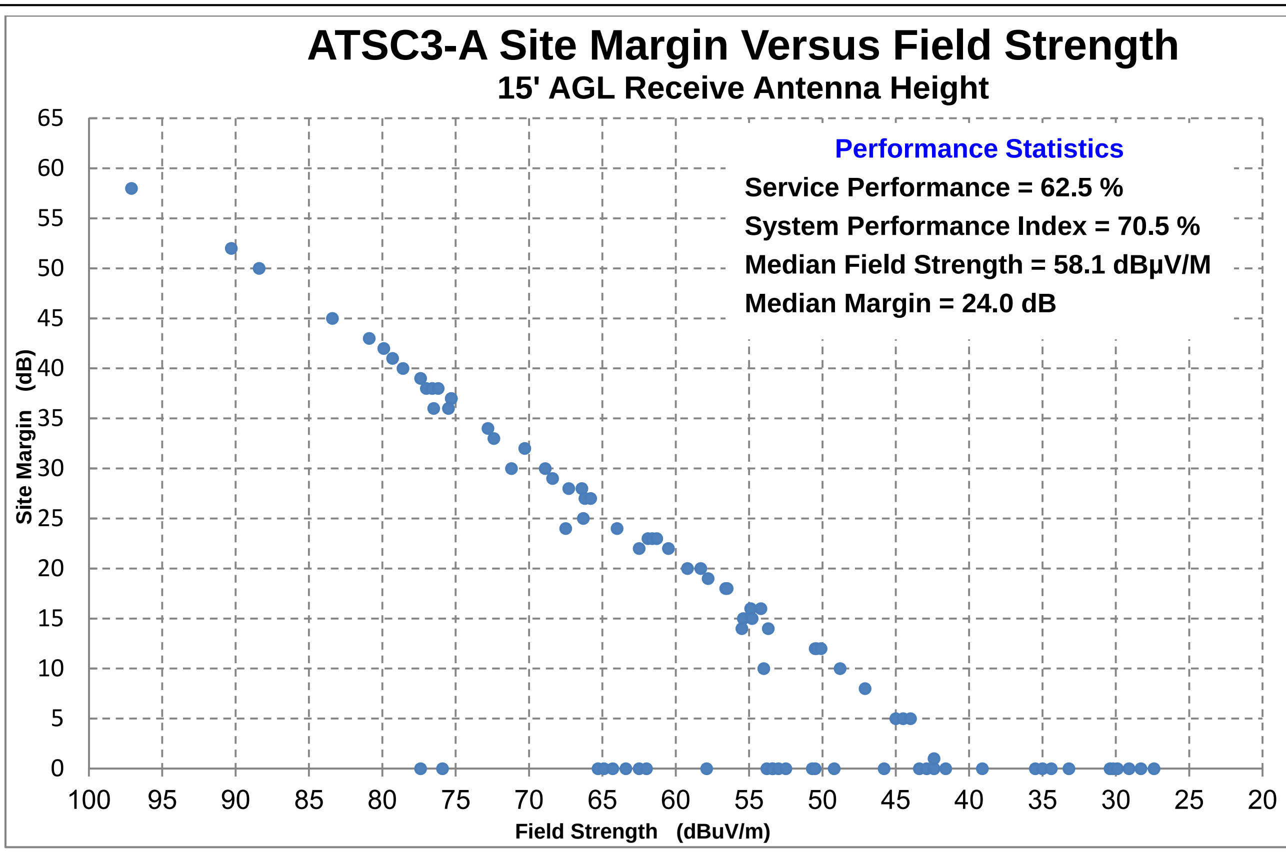


Figure A4-1d ATSC3-A field strength versus service margin plot at 15' AGL.

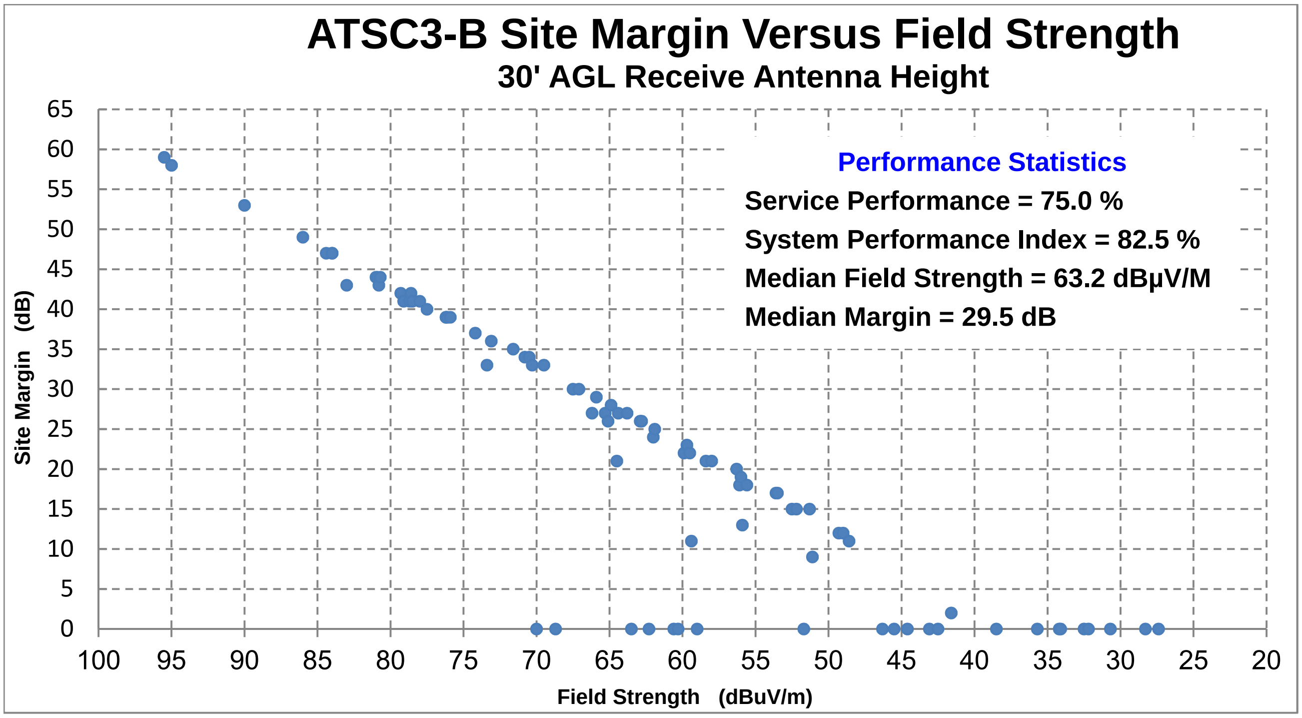


Figure A4-1e ATSC3-B field strength versus service margin plot at 30' AGL

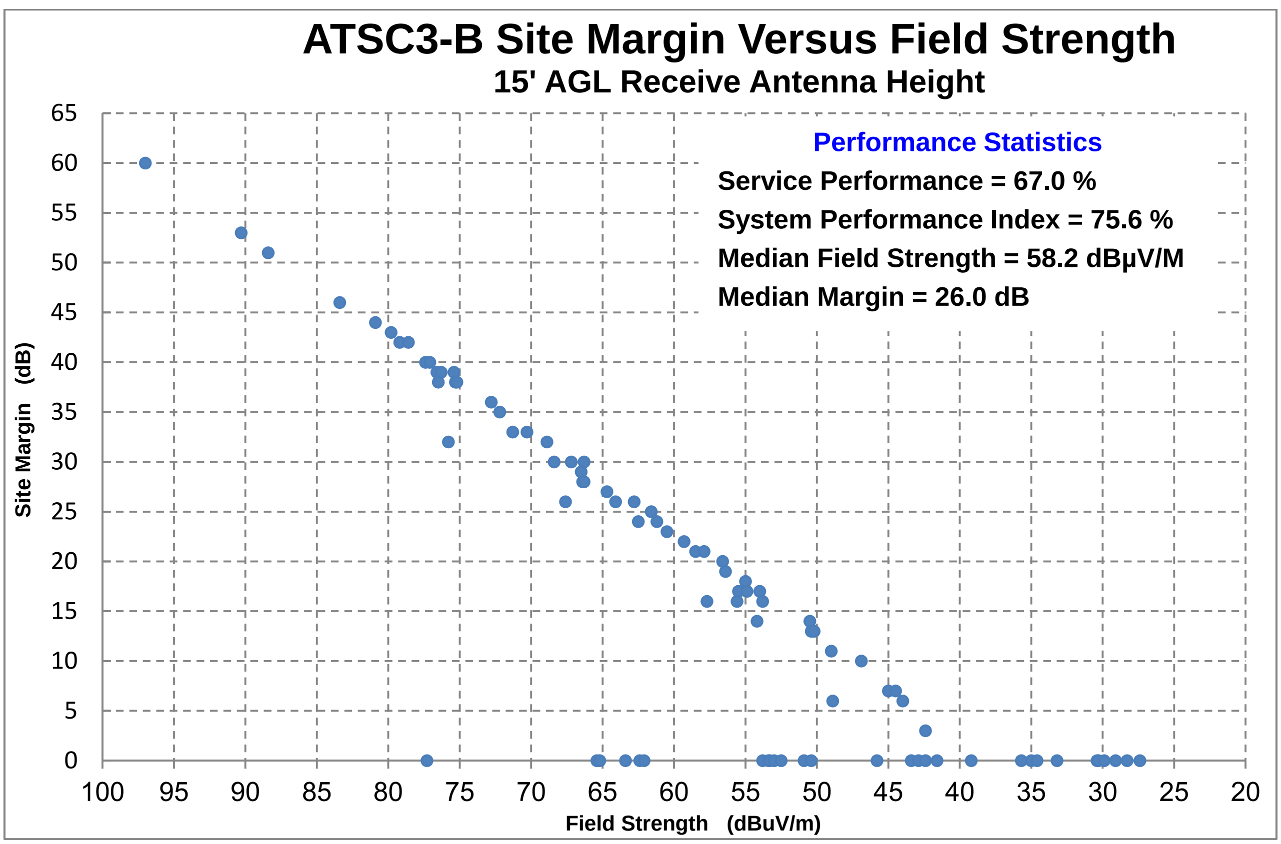


Figure A4-1f ATSC3-B field strength versus service margin plot at 15' AGL.

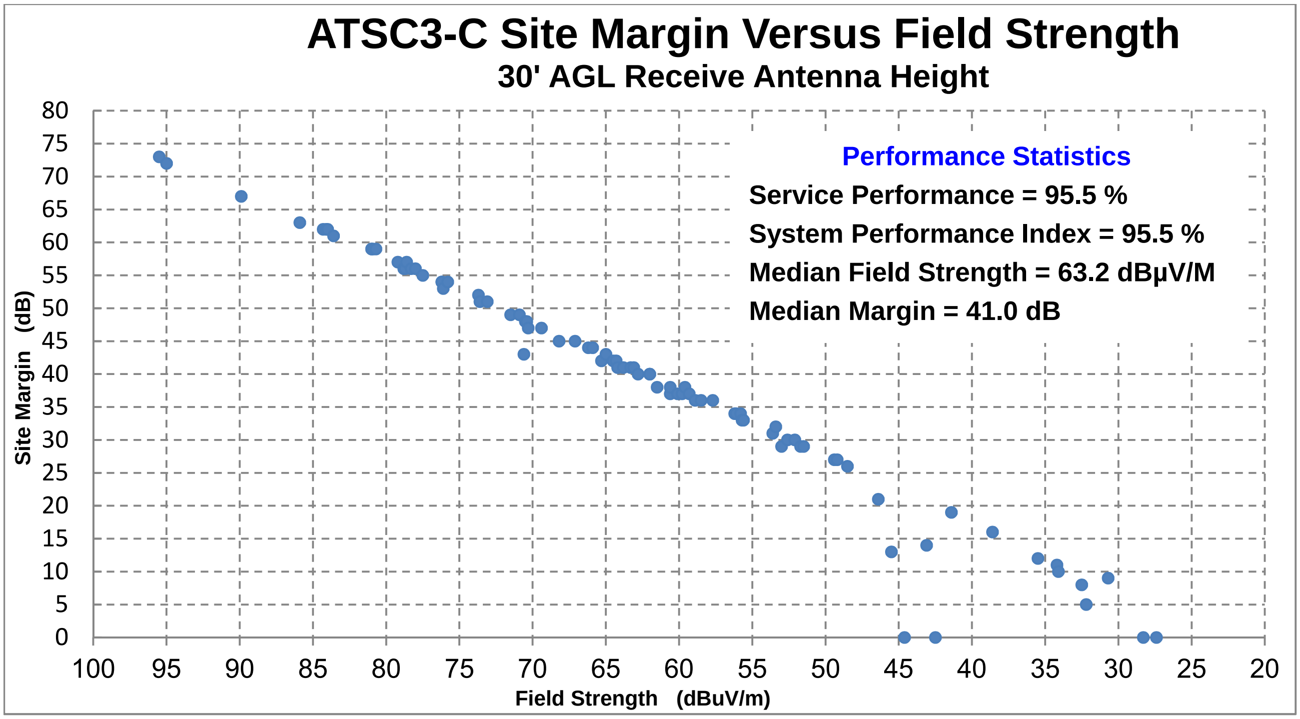


Figure A4-1g ATSC3-C field strength versus service margin plot at 30' AGL

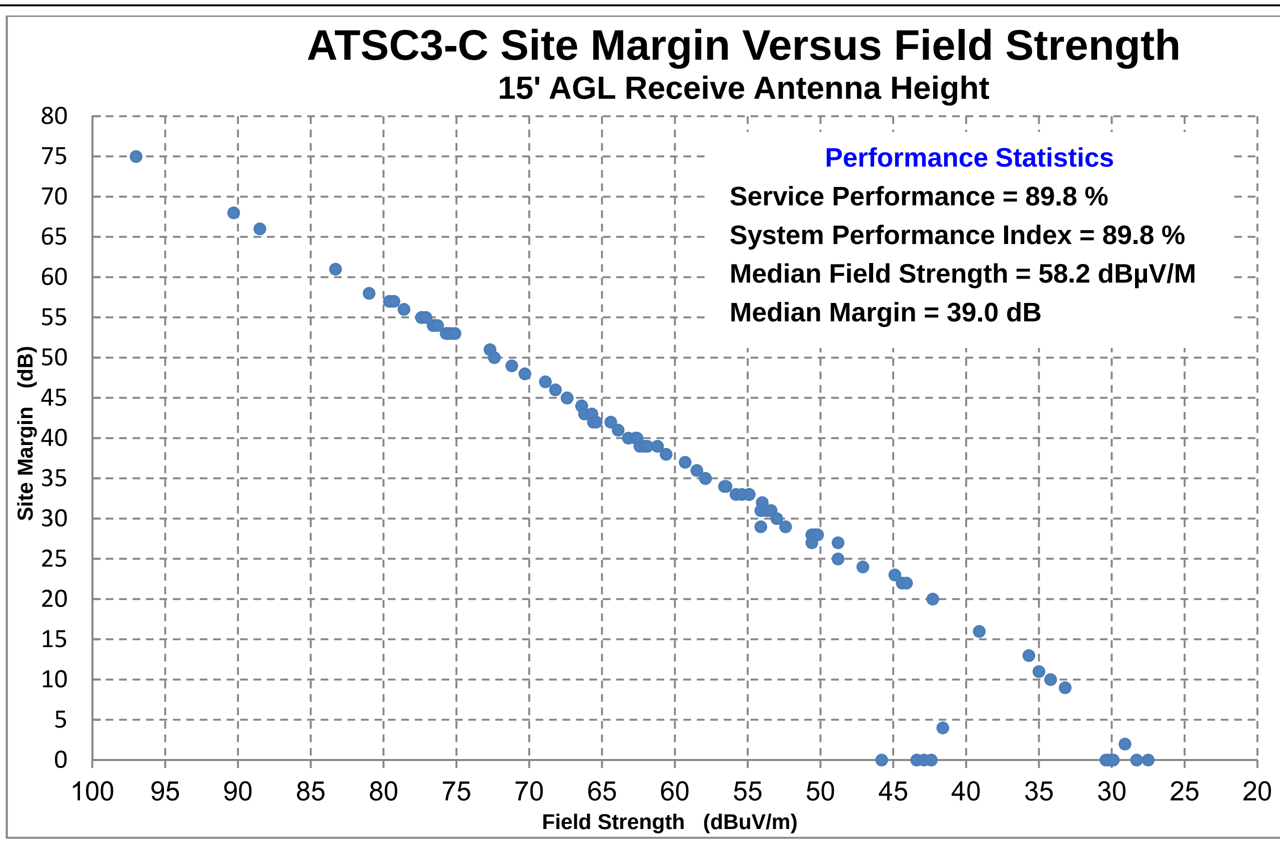


Figure A4-1h ATSC3-C field strength versus service margin plot at 15' AGL.

APPENDIX 5 ETRI LDM Field Test Results

The following pages are the results of the high-VHF LDM fixed and mobile field test in Cleveland, OH as provided by ETRI to NAB. The field test was performed over a couple of days in January 2016, just prior to the NAB field test that compared *fixed* reception of ATSC1 to 3 modes of ATSC3.

NAB Field Test Results

- **LDM only** -

Contents

Contents

- S-PLP and LDM configuration
- Laboratory Performance (in ETRI)
- Transmitter and Receiver (Test Vehicle) Setup
- LDM Fixed Reception Test (Core and Enhanced Layers)
- Mobile Reception Test (in Dennis Van) – Core Layer Only
- Mobile Reception Test (in Kelly rental car) – Core Layer Only
- Appendix: Some Pictures

S-PLP: Fixed Reception Mode - 1

- Frame length (symbol aligned mode): 251.34ms (including Bootstrap)
- Occupied BW = 5.832844MHz
- Preamble parameters
  - ✓ FFT size = 32k, SP_Dx = 12, Guard Interval = 148.148 us
  - ✓ L1-Basic/Detail mode 4
  - ✓ Number of preamble symbol = 1
- Payload OFDM parameters
  - ✓ FFT size = 32k, SP_Dx = 12, SP_Dy = 2, Guard Interval = 148.148 us, Pilot Boosting: max
  - ✓ Number of payload symbols = 50
  - ✓ Time Interleaver: CTI with a depth of 1024,
  - ✓ Frequency Interleaver: ON
- Payload BICM parameters
  - ✓ Inner code: 11/15-LDPC (64800)
  - ✓ Outer code: BCH
  - ✓ Constellation: 64-NUC
- Payload data rate & AWGN SNR:
  - Data rate = **23.1667 Mbps**
  - SNR = **14.28 dB** (**BICM performance**) ➔ SNR = **14.98 dB** (**including OFDM chain**)

S-PLP: Fixed Reception Mode - 2

- Frame length (symbol aligned mode): 249.63ms (including Bootstrap)
- Occupied BW = 5.832844MHz
- Preamble parameters
  - ✓ FFT size = 32k, SP_Dx = 8, Guard Interval = 527.78 us
  - ✓ L1-Basic/Detail mode 3
  - ✓ Number of preamble symbol = 1
- Payload OFDM parameters
  - ✓ FFT size = 32k, SP_Dx = 8, SP_Dy = 2, Guard Interval = 527.78 us, Pilot Boosting: 5.3 dB
  - ✓ Number of payload symbols = 46
  - ✓ Time Interleaver: CTI with a depth of 1024
  - ✓ Frequency Interleaver: ON
- Payload BICM parameters
  - ✓ Inner code: 10/15-LDPC (64800)
  - ✓ Outer code: BCH
  - ✓ Constellation: 64-NUC
- Payload data rate & AWGN SNR:
  - Data rate = **19.0369 Mbps**
  - SNR = **12.88 dB** (**BICM performance**) ➔ SNR = **13.64 dB** (**including OFDM chain**)

S-PLP: Robust Reception Mode

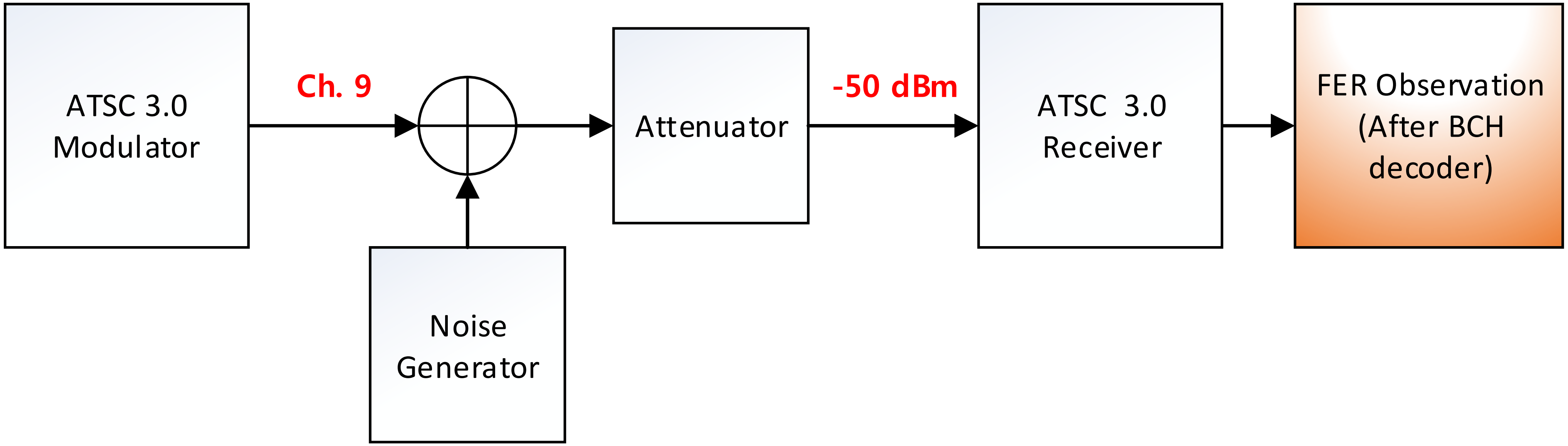
- Frame length (symbol aligned mode): 251.34ms (including Bootstrap)
- Occupied BW = 5.832844MHz
- Preamble parameters
  - ✓ FFT size = 16k, SP_Dx = 6, Guard Interval = 148.148 us
  - ✓ L1-Basic/Detail mode 1
  - ✓ Number of preamble symbol = 1
- Payload OFDM parameters
  - ✓ FFT size = 16k, SP_Dx = 6, SP_Dy = 2, Guard Interval = 148.148 us, Pilot Boosting: max
  - ✓ Number of payload symbols = 98
  - ✓ Time Interleaver: CTI with a depth of 1024
  - ✓ Frequency Interleaver: ON
- Payload BICM parameters
  - ✓ Inner code: 5/15-LDPC (64800)
  - ✓ Outer code: BCH
  - ✓ Constellation: QPSK
- Payload data rate & AWGN SNR:
  - Data rate = **3.2333 Mbps**
  - SNR = **-1.7 dB** (**BICM performance**) ➔ SNR = **-0.9 dB** (**including OFDM chain**)

Two-layer LDM Mode

- Frame length (symbol aligned mode): 272.49ms (including Bootstrap)
- Occupied BW = 5.832844MHz
- Preamble parameters
  - ✓ FFT size = 16k, SP_Dx = 8, Guard Interval = 111.11 us
  - ✓ L1-Basic/Detail mode 1
  - ✓ Number of preamble symbol = 1
- Payload OFDM parameters
  - ✓ FFT size = 16k, SP_Dx = 8, SP_Dy = 2, Guard Interval = 111.11 us, Pilot Boosting: max
  - ✓ Number of payload symbols = 108
  - ✓ Time Interleaver: CTI with a depth of 1024
  - ✓ Frequency Interleaver: ON
- Payload BICM parameters
  - ✓ Core layer
    - Inner code: 3/15-LDPC (64800), Outer code: BCH
    - Constellation: QPSK
  - ✓ Enhanced layer
    - Inner code: 11/15-LDPC (64800), Outer code: BCH
    - Constellation: 64-NUC
  - ✓ Injection level = -1 dB
- Payload data rate & AWGN SNR:
  - Core layer: Data rate = **2.0066 Mbps,** SNR = **-0.27 dB** (**BICM performance**) ➔ SNR = **0.49 dB** (**including OFDM chain**)
  - Enhanced layer: Data rate = **22.3144 Mbps,** SNR = **17.82 dB** (**BICM performance**) ➔ SNR = **18.58 dB** (**including OFDM chain**)

Contents

Laboratory Test Set-up



- Transmission channel: Ch. 9 (189 MHz)
- Rx power: -50 dBm (moderate)
- CNR Measurement step: 0.1 dB
- Measurement error due to fluctuation of signal and noise power ➔ at least ±0.1 dB error
- Target FER = 10^{-4}

Laboratory Performance in ETRI

◆ Performance under AWGN channel

Tx. Ch.	Rx. Power [dBm]	S-PLP						Two-layer LDM			
		Fixed-1 [dB]		Fixed-2 [dB]		Robust [dB]		Core-layer [dB]		Enhanced-layer [dB]	
		Ideal	Lab.	Ideal	Lab.	Ideal	Lab.	Ideal	Lab.	Ideal	Lab.
Ch. 9	-53	14.98	16.04	13.64	14.62	-0.9	0.1	0.49	2.82	18.58	19.72

◆ Minimally required signal power for stable reception

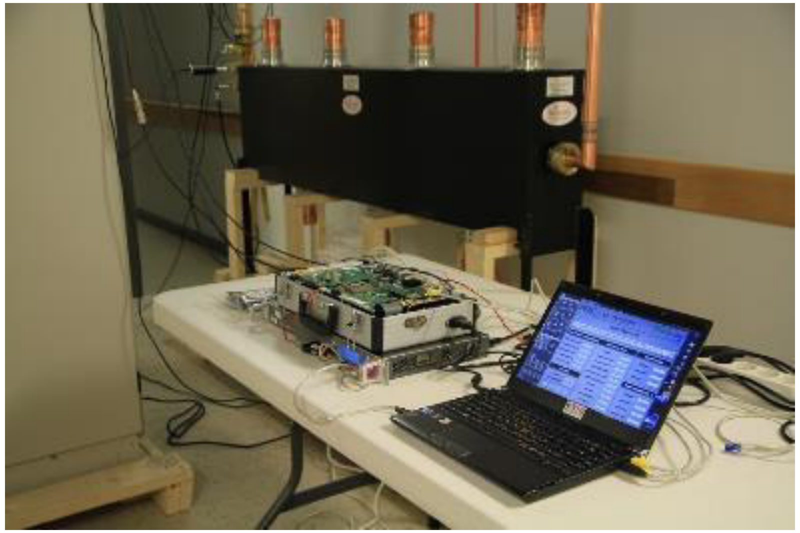
Tx. Ch.	S-PLP			Two-layer LDM	
Ch. 9	Fixed-1 [dBm]	Fixed-2 [dBm]	Robust [dBm]	Core-layer [dBm]	Enhanced-layer [dBm]
	-85.3	-86.2	-100.25	-97.5	-80.04

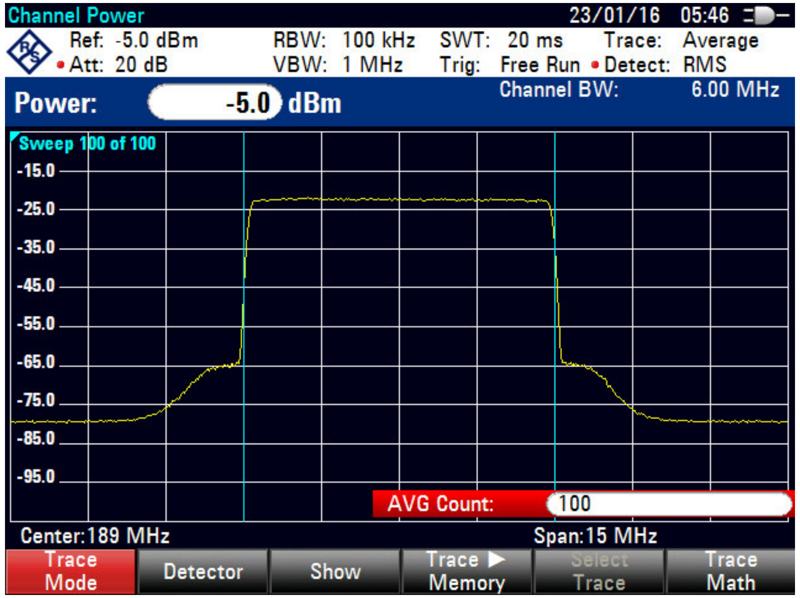
Reception performance in real field environment will be pretty worse than laboratory results.
Due to limited time, only S-PLP performance was well-optimized !!

Contents

- S-PLP and LDM configuration
- Laboratory Performance (in ETRI)
- Transmitter and Receiver (Test Vehicle) Setup
- LDM Fixed Reception Test (Core and Enhanced Layers)
- Mobile Reception Test (in Dennis Van) – Core Layer Only
- Mobile Reception Test (in Kelly rental car) – Core Layer Only
- Appendix: Some Pictures

Transmitter Set-up (4kW HPA output, Ch. 9 (189 MHz))



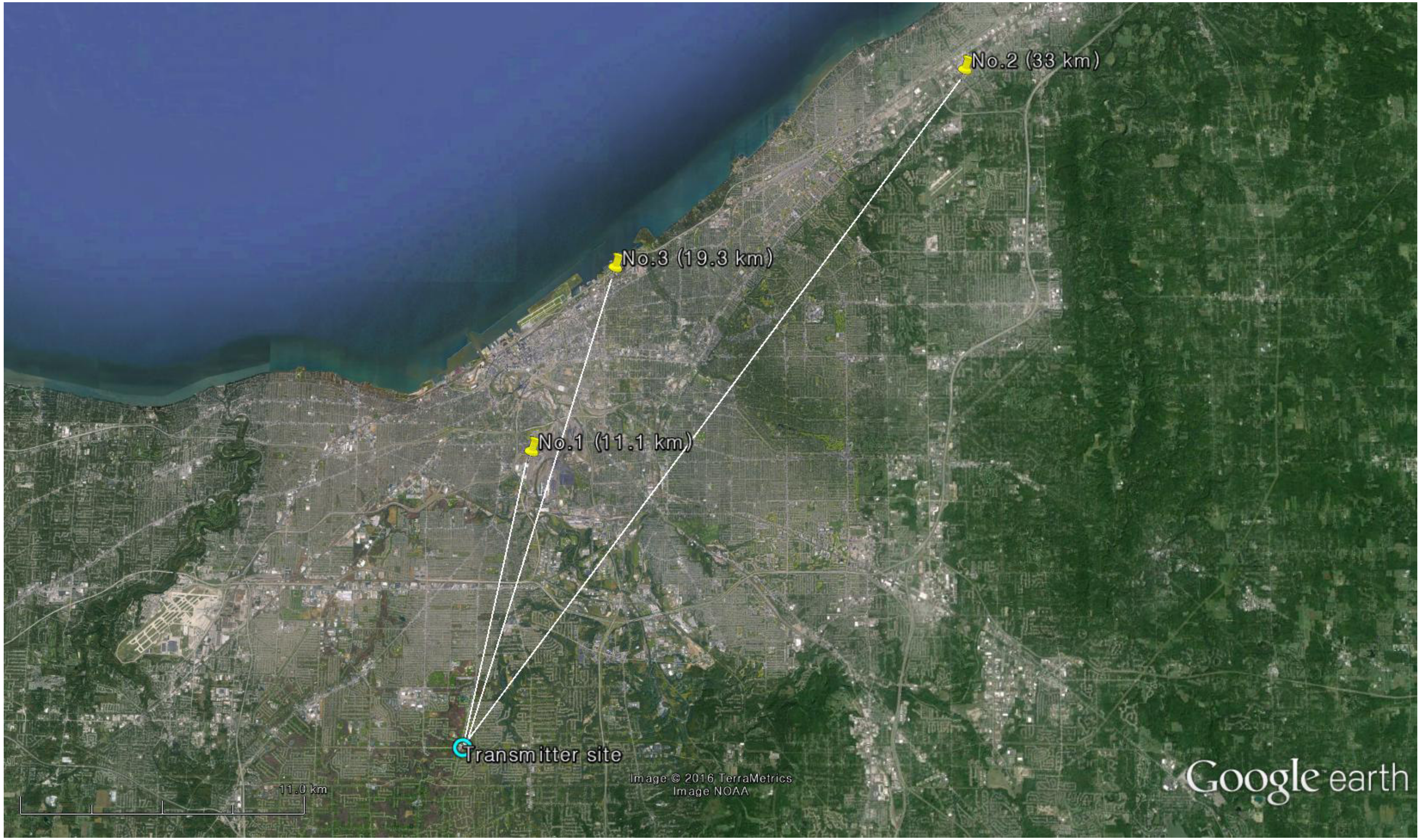


Test Vehicle Set-up

Contents

- S-PLP and LDM configuration
- Laboratory Performance (in ETRI)
- Transmitter and Receiver (Test Vehicle) Setup
- LDM Fixed Reception Test (Core and Enhanced Layers)
- Mobile Reception Test (in Dennis Van) – Core Layer Only
- Mobile Reception Test (in Kelly rental car) – Core Layer Only
- Appendix: Some Pictures

Map Information for Fixed Reception Test



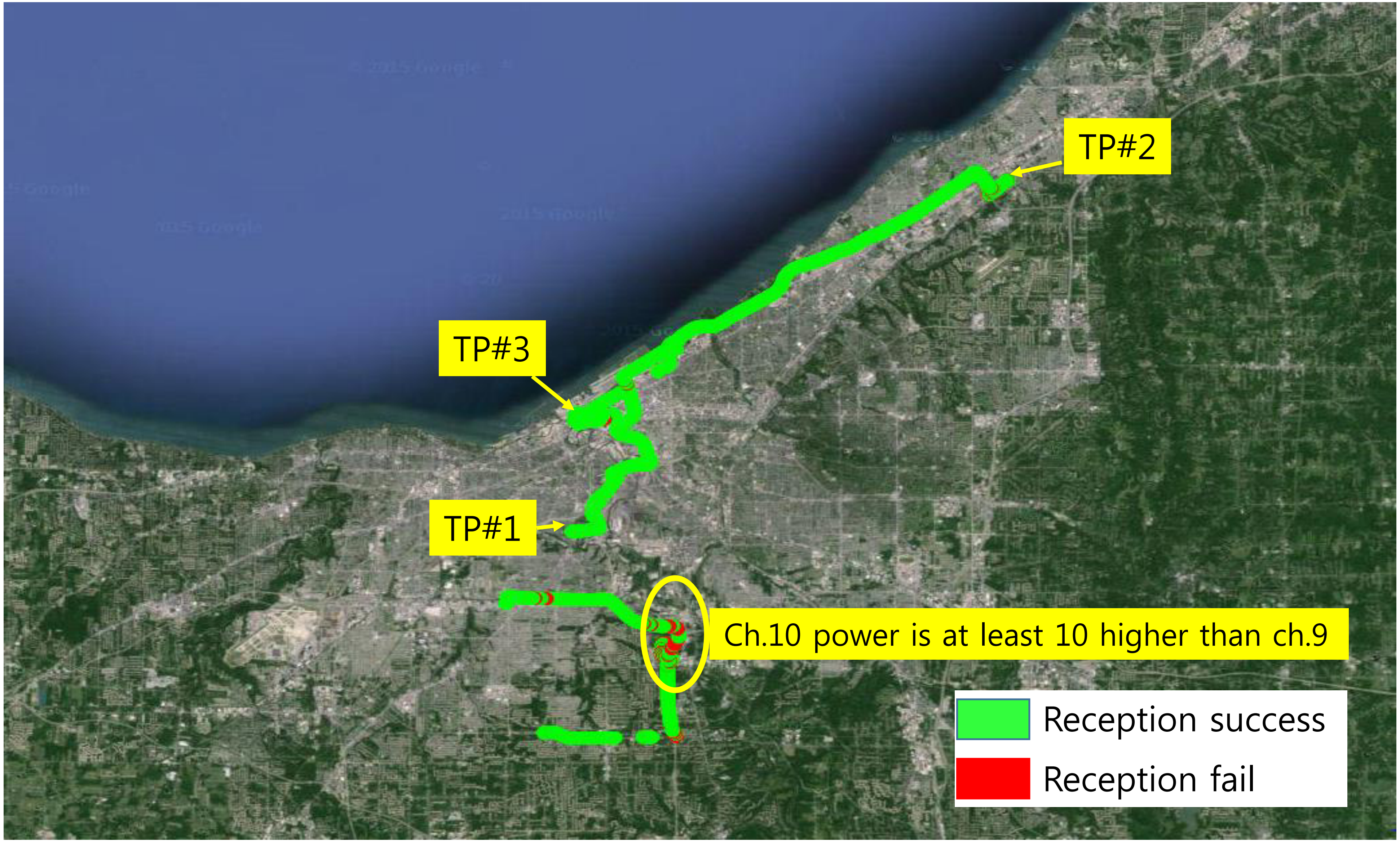
TOV Measurement in Fixed Reception

Test Point	LDM	
	Core-layer [dB] Ideal: 0.49, Lab: 2.82	Enhanced-layer [dB] Ideal: 18.58, Lab: 19.72
#1	3.8	21.4
#2	2.7	21.6
#3	2.9	21.8

Field performance is less than 1 dB away from laboratory result.
Laboratory performance was measured under AWGN channel w/o adjacent channel.

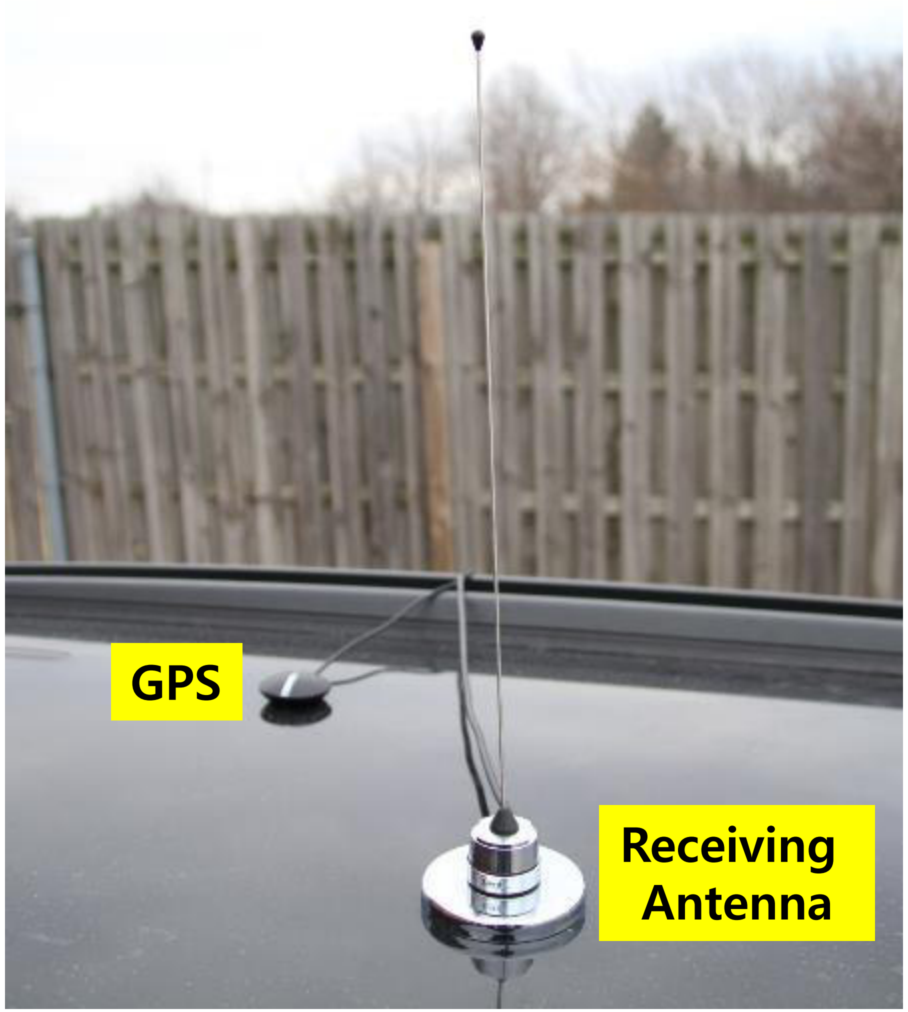
Contents

Mobile Measurement (LDM Core-layer only)

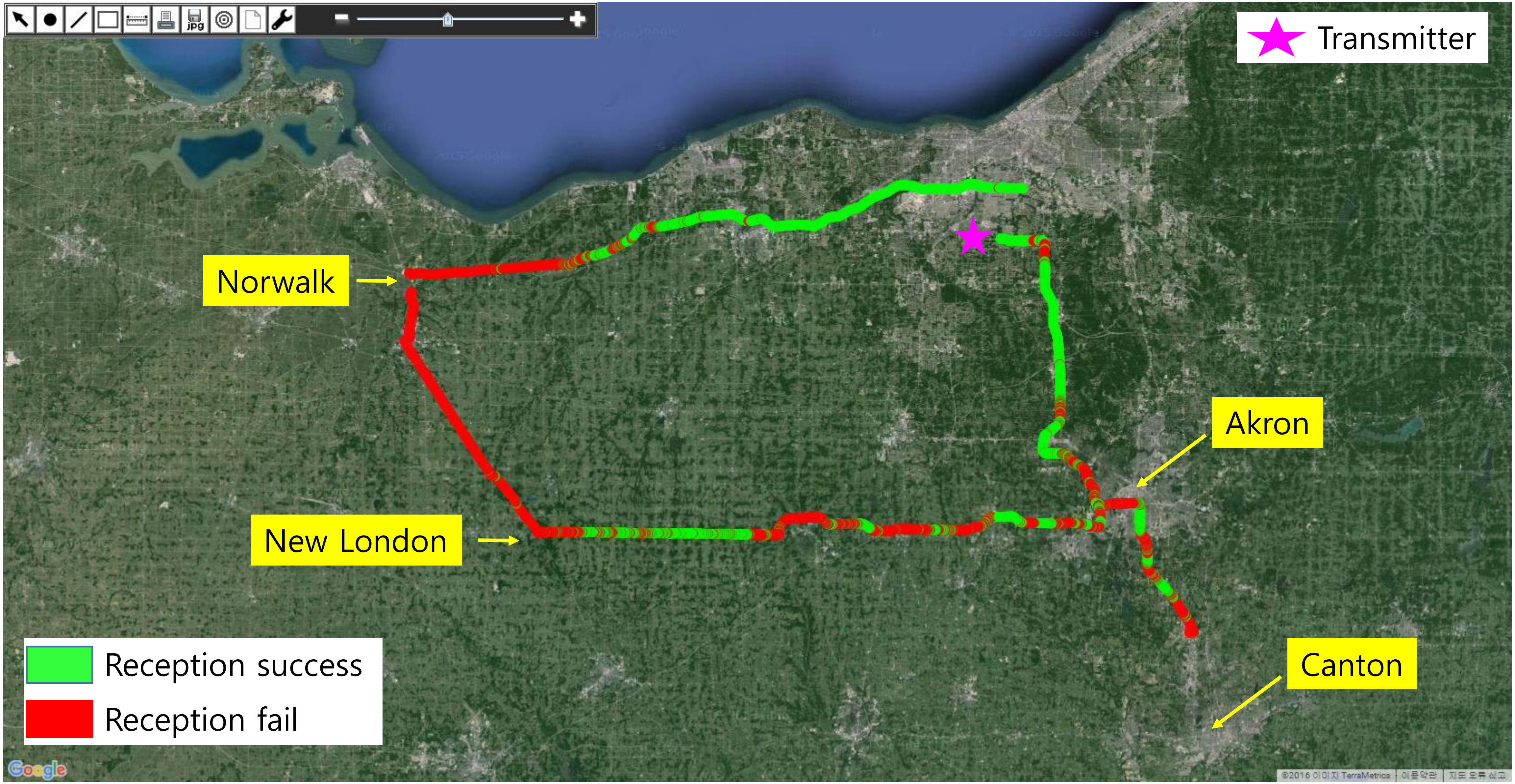


Contents

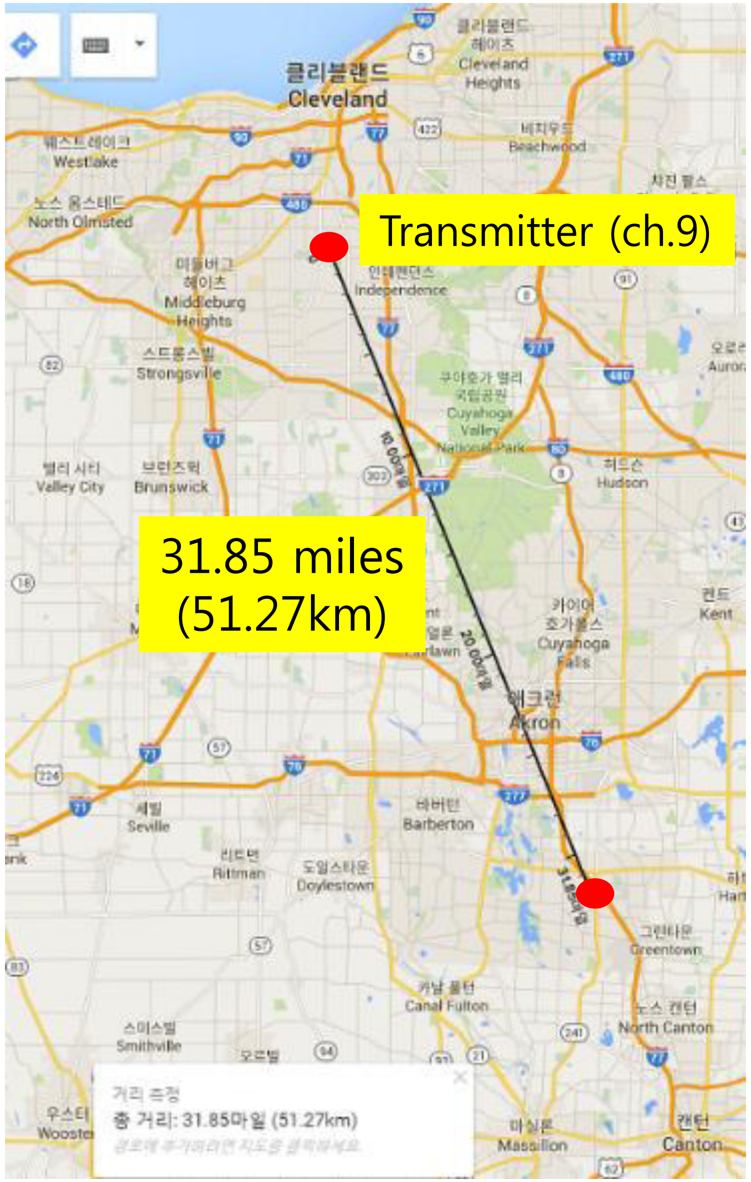
Test Vehicle Setup and Reception Antenna

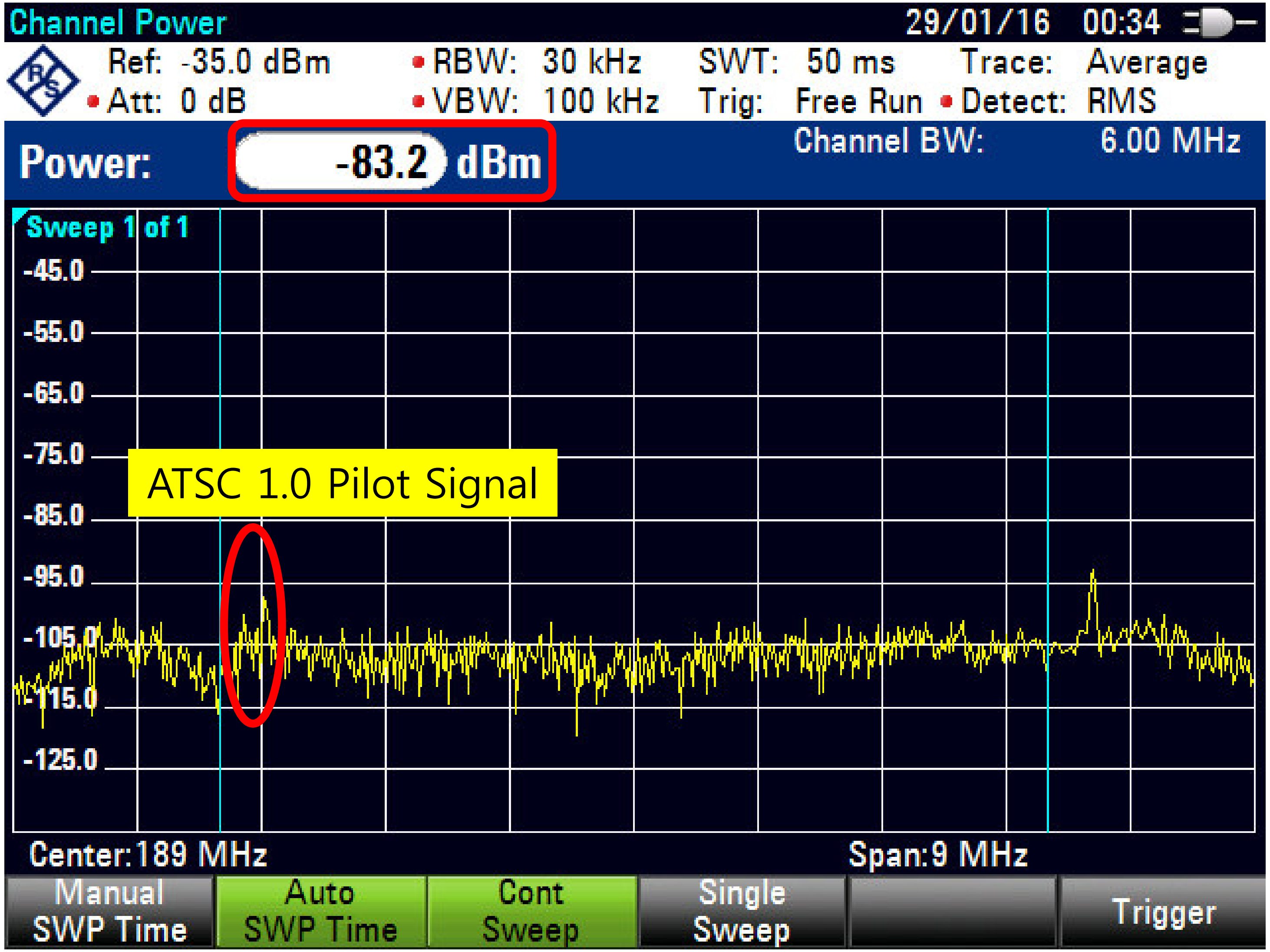


Mobile Measurement (LDM Core-layer only)

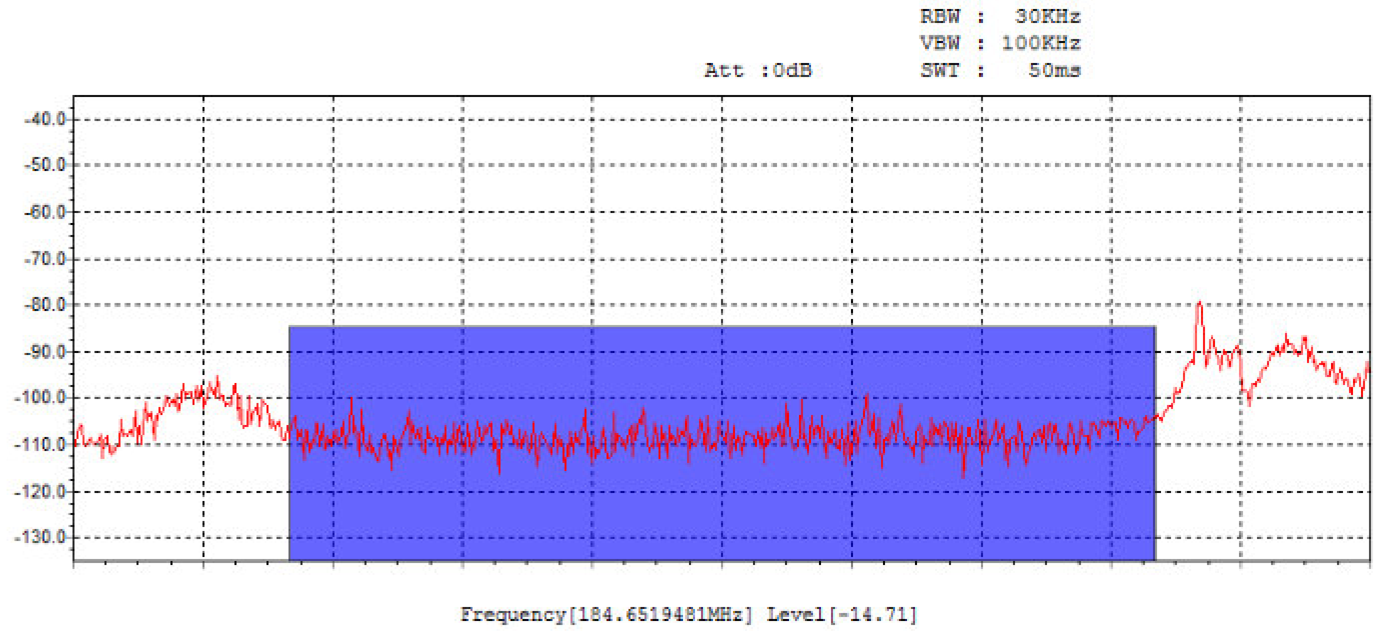


Co-channel Interference (Fixed Measurement)





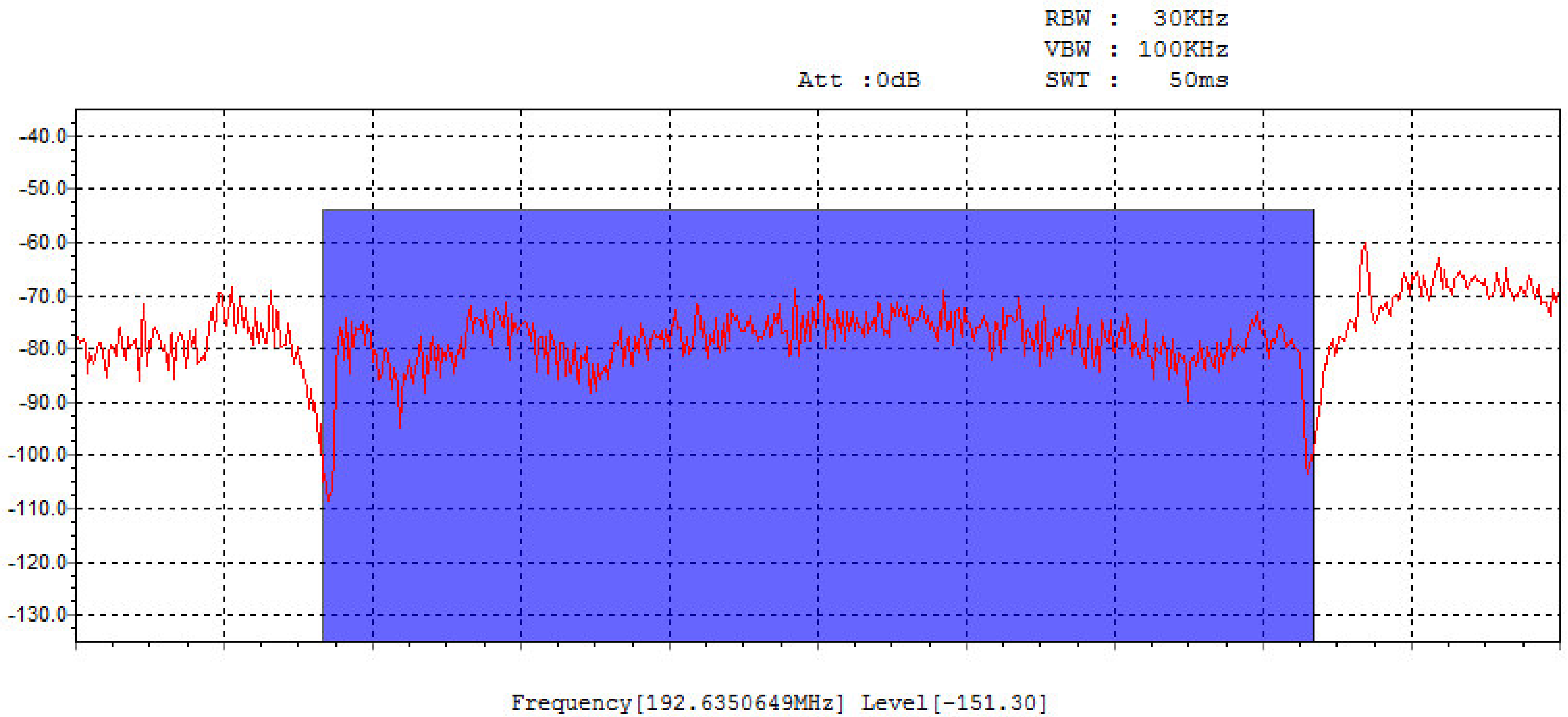
Co-channel Interference (Fixed Measurement)



NO	DATETIME	Logitude	Latitude	Level	EFS	TotalFrame	ErrorFrame	SNR
4095	2016-01-29 01:15:42	81.907303	41.031835	-76.66	46.09	50	0	6.2
4094	2016-01-29 01:15:42	81.907295	41.031832	-76.94	45.81	50	0	6.0
4093	2016-01-29 01:15:41	81.907295	41.031832	-76.07	46.68	50	0	6.6
4092	2016-01-29 01:15:41	81.907272	41.031827	-76.07	46.68	50	0	8.5
4091	2016-01-29 01:15:40	81.907272	41.031827	-71.06	51.69	50	0	13.2
4090	2016-01-29 01:15:40	81.907242	41.031815	-70.18	52.57	50	0	12.4
4089	2016-01-29 01:15:39	81.907242	41.031815	-72.04	50.71	50	0	11.8
4088	2016-01-29 01:15:39	81.907210	41.031797	-72.04	50.71	50	0	11.6
4087	2016-01-29 01:15:38	81.907210	41.031797	-73.05	49.70	50	0	11.2

Transmitter off: -84.2 dBm, Transmitter on: -76.7 dBm
➔ CL successful reception (Measured SNR in ETRI Rx = 6dB)

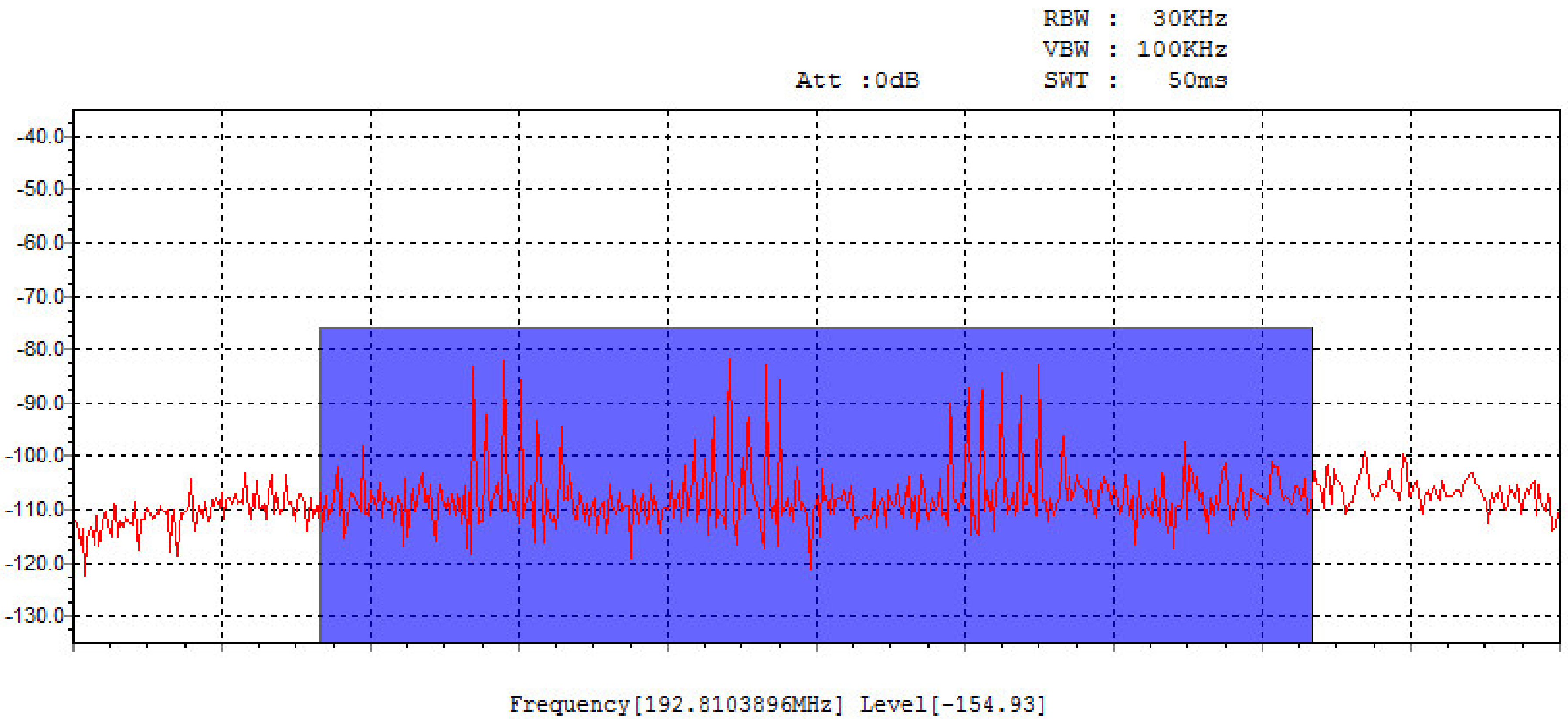
Good Mobile Reception: Example



NO	DATETIME	Logitude	Latitude	Level	EFS	TotalFrame	ErrorFrame	SNR
4697	2016-01-29 05:28:58	81.875677	41.422732	-53.92	68.83	50	0	25.1

Rx. Power = -53.9 dBm
Measured SNR in ETRI Rx = 25 dB

Unknown Impulse Noise



Unknown impulse noise was observed in one place

Appendix

Fixed Test Point #1: Steel factory area

Fixed Test Point #2: Antenna store

Fixed Test Point #3: FOX8 studio